THE UNIVERSITY OF ALBERTA

"FABABEANS AND CASSAVA AS DIETARY INGREDIENTS FOR GROWING PIGS"

by

GREGORY TONY UWUIGBE ONAGHISE (C)

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Fababeans and cassava as dietary ingredients for growing pigs", submitted by Gregory T. U. Onaghise, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science in Animal Nutrition.

J P Bowland
.....
Supervisor

.....

.....

Date April 14, 1976

TO MY MOTHER

MADAM EGBEMWENOGHAYE ONAGHISE

ABSTRACT

Fababeans (FB) (Vicia faba L. minor) and cassava (Manihot esculenta Crantz) are potential alternative protein and energy sources respectively for replacement of soybean meal (SBM) and cereal grains in pig diets in order to reduce cost of feeding and competition with humans. Increased knowledge of the relative and intrinsic worths of FB and cassava would facilitate their optimum utilization to achieve these goals.

One hundred and twenty crossbred weanling pigs were used in an experiment to study the effects of partial or total replacement of SBM by ground unprocessed FB and of 0, 20 and 40% cassava in the diet. Evaluation criteria were average daily feed intake (FI), average daily gain (ADG), efficiency of feed conversion (EFC), carcass traits, energy and nitrogen digestibilities and thyroxine (T4), and triiodothyronine (T3) levels in the plasma. There were 15 dietary treatments and four pigs per treatment replicated twice during the starting phase (9 wk.). At the end of this phase, all pigs were fed the respective 0% cassava diets, making a total of 5 dietary treatments during the finishing phase. Energy and nitrogen digestibilities were determined by both the 4N-HCl and total collection methods.

During the starting phase, partial replacement of SBM by FB or FB supplemented with lysine and methionine had no significant effects on FI, ADG or EFC. Total replacement of SBM with FB, even when supplemented with lysine and methionine, produced significantly lower ($P<0.01$) FI and ADG

than did the SBM or SBM-FB diets. Lysine and methionine supplementation of the diets with FB as the sole supplement significantly improved ADG and EFC. Cassava inclusion at a level of up to 40% did not significantly reduce FI, ADG or EFC in any of the dietary groups.

Energy and nitrogen digestion coefficients by the total collection method were significantly higher ($P<0.01$) than those by the 4N-HCl method. There were no significant differences between treatments for digestible energy (DE) by the total collection method or digestible nitrogen (DN) by either method. The feeding of cassava had no significant effect on plasma T3 or T4 levels within treatment groups.

During the finishing phase, partial or total replacement of SBM by FB had no significant effect on EFC. The FB diet supplemented with lysine and methionine produced FI and ADG significantly lower than SBM or SBM-FB diets. Slaughter age was increased for pigs fed the sole FB diet. Carcass weight and total backfat were reduced for pigs fed sole FB diets unsupplemented with lysine and methionine but other carcass measurements were not influenced by treatment.

The results indicate that ground unprocessed FB, supplemented with lysine and methionine, can fully replace SBM in the diets of finishing pigs but not starting pigs. Cassava can be included in the diet of starting pigs at up to 40% of the diet without significantly affecting performance when appropriate adjustments are made in supplemental protein levels or in lysine levels of the diets.

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INTRODUCTION

The ever increasing world population demands a continued interest in increasing the quantity and quality of food produced to meet the needs of these new generations and thus reduce the problems of hunger, malnutrition and kwashiokor that are so prevalent in the world today. In helping to develop and expand the animal industry to meet this demand, the animal nutritionist must try to reduce competition between the human and animal populations for available energy and protein sources.

Pigs require large quantities of energy and moderate quantities of protein for their growth and development. In many developing countries, the annual production of cereal grains is not enough to satisfy the needs of the human population, much less livestock. However, large quantities of other potential feedstuffs exist if they can be incorporated into efficient and economical rations for pigs. Even in the large pork producing countries, grains are getting short for livestock feeding. In 1973, the American and Canadian pork producer was faced with the highest feed grain and protein supplement prices ever recorded (Tanksley, 1973). Improved cereal and oilseed production has resulted in only partial relief in the years since 1973.

Research studies by swine nutritionists have thus been accelerated to find cheaper and less competitive protein and energy sources for pig feeding without sacrificing performance. The study reported herein was part of this

effort. It was designed to evaluate the feeding value of fababeans and cassava for growing-finishing pigs. The effects of feeding a lower level of protein than recommended by the National Research Council (NRC) 1973 and the influence of supplementation with lysine, methionine and cystine on the performance of pigs were also studied. The parameters measured in the study were feed intake (FI), average daily gain (ADG), efficiency of feed conversion (EFC), carcass characteristics and blood thyroxine (T4) and uptake of triiodothyronine (T3) levels. The study was undertaken at the Edmonton Research station of the Department of Animal Science, The University of Alberta between April, 1975 and January, 1976.

LITERATURE REVIEW

Protein and Amino Acids

Protein supplementation of diets for the growing pig demands a knowledge of the pig's requirements, so that the composition of suitable rations can be decided. This knowledge requires an accurate definition of the changes in morphological, chemical, enzymatic, and physiological characteristics during the growth of the animal (Rérat, 1972).

Experiments with the growing-finishing pig show that the lipid proportion of carcasses is low at birth, increases rapidly during the first three weeks, stabilizes until after weaning and then increases again. At the same time the proportion of lean in carcass decreases gradually during growth.

Muscle tissue is synthesized from the protein in the diet. Since the objective of swine production is to produce lean-type pigs, it is necessary that the protein supply, and more particularly, the essential amino acid supply should provide the daily optimum for the required body and growth characteristics. When the supply is sub-optimal, tissue proteins are broken down to supply amino acids for the synthesis of essential body proteins. Thus in protein feeding of pigs we are guided by the basic laws governing lean meat and fat formation (Clausen, 1965).

1. No pig can form lean meat up to the limit determined by its heredity unless its diet contains sufficient

quantities of protein of high biological value.

2. When the pig's daily requirements for maintenance and lean meat production have been met, the rest of the ration must inevitably be used for the formation of fat.

The above statements recognize the fact that body nitrogen has its origin in the proteins contained in its food and that these proteins differ in nutritional quality. The reason for the difference in nutritional quality of protein did not come to light until the pioneering work of Hopkins (1906) and of Osborne and Mendel (1914) which gave rise to the concept of dispensable and indispensable amino acids. This concept indicated that the nutritive value of a protein is related to its amino acid composition. Further studies (Rose, 1938) revealed that the nutritional quality of a protein depends not only on its amino acid composition and the specific amino acid requirement of the animal but also on the availability of the amino acids in the protein. Thus the idea of availability as distinct from total amino acids present in a dietary protein is important in determining the ability of a protein to supply the requirements of the animal. Therefore subject to variations in digestion and absorption, the protein which can meet the requirement of the animal is that which can supply all the essential amino acids needed in the proportion most nearly like that in which they exist in the tissue to be formed plus an appropriate non-specific source of nitrogen to form non-essential acids. The reports of Elman (1939) and Melnick

et al. (1946) emphasize that protein synthesis does not occur unless a complete mixture of the essential amino acids is present at one time.

Jones et al. (1967) indicated that an excess or deficiency of some amino acid may lead to an overall depression in amino acid availability. Jones (1964) had earlier shown the influence of excess lysine on the reduced availability of arginine to chicks. Harper et al. (1970) and Chamberlain (1971) stated the following as conditions under which amino acids can affect protein utilization: (1) amino acid imbalance, (2) amino acid antagonism, (3) amino acid toxicity. Any of the above conditions are now known to influence the performance of pigs.

Protein Requirements

Various studies have been carried out over the years to determine the optimum levels of protein and amino acids for the growing pig. Most of these experiments have been aimed at determining a difference in response to different concentrations of crude protein.

Woodman et al (1939) indicated that pigs would grow satisfactorily on lower levels of protein than recommended at that time. Woodman and Evans (1940, 1941, 1948) therefore directed their studies to determining the minimum levels of protein intake consistent with rapid growth rate and satisfactory carcass quality. They found that a diet consisting of cereals and wheatings and supplying 7% fish

meal (FM) and 15% crude protein gave satisfactory results when fed to bacon pigs from weaning to 41 kg live weight.

The protein requirements of the growing pig were extensively reviewed by the Agricultural Research Council (ARC) (1967). The ARC remarked that it is difficult to distinguish between responses to the different crude protein levels used because most of the experiments were not sufficiently sensitive or large enough in scale to allow determinations of optimum levels of crude protein required. Maximal response appeared to be approached asymptotically in most of the experiments. The general impression from the data reviewed by ARC is that if the level of protein is unchanged from weaning to 90 kg live weight, and antibiotics are not used, 16% crude protein will yield satisfactory growth rate and feed efficiency for pigs fed ad libitum. When the diet is changed from growing to finishing, the literature reviewed suggests that for optimum ADG and EFC, the crude protein requirement up to 45-50 kg live weight is 18.5-20% on a dry matter basis and from this weight to slaughter, 15-16 percent.

Bowland (1970) compared the effects of different levels of protein on the performance and carcass quality of pigs from 7 to 86 kilogram. The diets offered in the three stages (starting, growing and finishing) contained 20, 17, 14; 20, 14, 14; 17, 17, 17; 14, 14, 14 or 14, 14, 14% crude protein supplemented with L-lysine and DL-methionine in the starter phase. The results showed that the performance of the pigs fed the 17% crude protein throughout was as good in ADG, EFC

and carcass quality as those fed higher levels of protein in the starting period. The pigs on the 14% crude protein or the 14% crude protein supplemented with lysine and methionine were inferior in performance to the pigs on the other treatments and required more days to reach market weight.

Pierce and Bowland (1972) reported a similar experiment to the above but with some modification. Treatments 1, 2, 3, 4 were the same as the ones reported above. In treatment 5, the 14% protein supplemented with lysine and methionine was fed to the pigs during the starting, growing and finishing stages. An additional treatment with 14% protein supplemented with lysine alone was included and fed to the pigs during the starting, growing and finishing periods. These latter protein levels were lower than recommended by National Academy of Sciences-National Research Council (NAS-NRC) (1968) for pigs of the same age and live weight. They found that FI, ADG and EFC were inferior in the starter phase for the pigs fed 14% protein throughout compared with the other dietary combinations. Amino acid supplements improved FI, ADG and EFC compared with the 14% protein diet but lysine and methionine as dietary additions in combination did not appear to have any beneficial effect over lysine added alone. They therefore suggested that the total sulfur amino acid (methionine and cystine) requirements of pigs are probably lower than recommended by NAS-NRC (1968).

Kornegay et al. (1973) used several protein sequences

from 16-16-16 to 12-12-12 and three protein levels (16,14, 12%) to evaluate the effects of dietary protein level on pig performance and carcass quality. They concluded that a protein level sequence of 16-16-14 or 16-14-14 in corn-soybean diets optimized gain, EFC and carcass quality. The pigs fed the lower protein sequences (14-12-12 and 12-12-12) had poor carcasses and the cost per pound gain was higher. Kornegay et al (1973) fed a corn-based diet whereas Bowland (1970) and Pierce and Bowland (1972) fed diets based on barley and wheat. The difference in protein level of the basal cereals probably explains the differences in absolute levels of protein found to meet requirements.

McConnell et al. (1973) fed a 16% protein diet throughout the growing-finishing period and observed a slight improvement in rate of gain and feed efficiency compared with pigs changed to a 14% protein diet at 57 and 80 kg bodyweights respectively.

Mahan et al. (1973) fed four protein levels (14, 16, 18 and 20%) during the growing period and the same 13% protein diet to all treatments during the finishing period. They observed higher gains on the 16 and 18% protein diets than the 14 and 20% diets during the growing period. Feed efficiency however increased linearly as dietary protein levels increased up to 18 percent. During the finishing period, ADG and EFC decreased as dietary protein level fed during the growing period increased. This result suggested a compensatory growth during the finishing period for the pigs previously fed low protein diets.

Pay and Davies (1973) studied different levels of dietary protein (16, 18, 20%) for boars and reported no significant advantage in performance or carcass merit from feeding dietary protein above 16 percent. Weight gains were slightly higher on the 18 and 20% diets during the growing and finishing periods but resulted in essentially no advantage for the higher protein diets.

Davey and Frobish (1975) fed various protein sequences to 7-week-old pigs up to 90 kg live weight. The first group was fed a 16% protein diet throughout while the others received the following protein sequences 16-14-12; 16-12-12; 14-12-12 and a 12% protein diet supplemented with L-lysine to equal the 16% diet. The fastest overall ADG were made by those receiving the protein sequences 16-14-12 or 12% plus lysine and the best EFC by groups fed 16% protein throughout or 12% protein plus lysine.

It is evident that, because of variation in levels of essential amino acids, it is difficult to make firm recommendations on requirements on the basis of crude protein levels in pig diets.

Amino Acid Requirement and Supplementation

Amino acid supplementation of low protein diets and the effects on the performance of growing-finishing pigs are now being studied widely. Several reviews, including recommendations on requirements, have been published in recent years, (ARC, 1967; NAS-NRC, 1973; Rerat and Lougnan, 1968; Tanksley, 1973).

Tanksley (1973) suggested that on a corn-soybean meal low protein diet (12 and 10%), lysine proved to be the first limiting and tryptophan the second limiting essential amino acid during the growing and finishing phases. Aherne et al. (1974) suggested that lysine is the first limiting amino acid for pigs in wheat and barley-based diets. Tanksley (1973) put forward a hypothesis that the requirement for a limiting amino acid remains a constant percent of the dietary protein for protein levels ranging from subadequacy to adequacy.

Brown et al (1973a,b) re-evaluated the lysine requirement of finishing pigs using a 13.3% protein corn-sesame meal diet containing 3.50 Mcal Metabolisable Energy (M.E.)/kilogram. The results showed that the lysine requirement was 0.48% of the diet for maximum gain, 0.60% for maximum EFC, 0.51% for maximum lean cuts and 0.60% for maximum loin eye area.

ARC (1967) recommended minimum lysine levels of 0.9% in 18.5% crude protein (dry matter basis) for pigs up to 50 kg and 0.7% lysine in 15% crude protein for pigs from 50-90 kg live weight.

Increased response to lysine supplementation has been observed when tryptophan was added to the diet (Gallo and Pond, 1968). The superiority of Opaque-2 maize to "normal" maize has been attributed to higher concentrations of lysine (4.2% cf. 2.6%) and tryptophan (1.3% cf. 1.0%) in the crude protein. Cromwell et al. (1967) supplemented normal maize with these amino acids and got results similar to those

obtained with unsupplemented Opaque-2 corn. Tanksley (1973) indicated that if the widely varying tryptophan requirements given in the literature for pigs are recalculated using 80% availability factor for DL-tryptophan and the requirement is expressed as a percent of the protein, the values will come close to 0.70% for growing-finishing pigs.

Although methionine has been shown to be the first limiting amino acid in soybean protein, Berry et al. (1966) used diets based on maize, oats, barley and soybean meal and his results showed no advantage in adding this amino acid. This is probably because sufficient sulphur-containing amino acids are provided from the cereal component of the diet to ensure that sufficient methionine is available in the diet.

Numerous references appear in the literature reporting the response of pigs to amino acid supplementation of low protein diets. Representative experiments are discussed.

Bowland and Grimson (1969) showed that the addition of 0.57% lysine to diets containing 14% protein increased ADG and EFC of 3- to 9-weeks old weanling pigs to a level equivalent to that obtained with a 22% protein diet.

Thrasher and Simoneaux (1973) observed significantly faster ADG and improved EFC on a 16-14 protein sequence than on a 14-12% sequence. When the 14 and 12% diets were supplemented with 0.15% L-lysine, ADG and EFC were essentially the same as those obtained on the 16-14% protein sequence.

Wahlstrom and Libal (1973) obtained similar results to those of Thrasher and Simoneaux when they compared 17-14%

and 14-11% protein feeding regimens. Lysine supplementation (0.1 or 0.2%) of the 14-11% protein sequence improved feed efficiency while 0.2% methionine supplementation had no beneficial effects in the presence of lysine and depressed gain when added alone. Orr (1973) also observed no favourable response from the addition of 0.05% methionine to a 16% protein corn-soybean meal diet when fed to 10 kg pigs.

Newman and Elliot (1975) conducted two experiments to test the effect of lysine and/or methionine supplementation of a 14% barley-soybean meal diet on the performance of pigs of 23.6 kg initial weight. In experiment 1, both the amino acid supplemented diets produced slower ADG than the basal control containing 16-14% protein. However, in experiment 2, gains were faster in pigs fed the lysine alone or lysine and methionine supplemented diets than in those fed the basal control diets. They did not, however, observe any difference in either trial in ADG between pigs fed diets supplemented with lysine alone or with lysine plus methionine together.

Morris and Luckham (1975) observed increased ADG and improved EFC when lysine was added to 12 and 14% high moisture corn diets for pigs weighing 40 to 90 kg. There was no significant benefit in growth rate and EFC when methionine was added without lysine supplement.

The consensus of results is that lysine is usually the first limiting amino acid in cereal-based diets. Methionine seldom seems to be limiting in such diets. Supplemental lysine in the diet will replace a portion of the supplemental proteins normally required to obtain optimum

performance in diets based on cereal grains.

PROTEIN SOURCES

A. Fababeans as a Protein Source

History and extent of cultivation.

The small fababean (Vicia faba L. var. minor) is one of the two sub-divisions of the species Vicia faba L. The other sub-division of the species is Vicia faba major or broad bean. Common names for the small fababean are horse bean, field bean or tick bean. It is referred to by these different names in the various countries where it is produced. For the purpose of this report, the name fababean shall be used.

Although the fababean belongs to the Vicia (vetch) genus of the Papillionaceae, it will not cross with any other Vicia species and does not exist in wild forms. Unlike all other Vicia species, Vicia faba has poorly developed tendrils, the flower is whitish, the pods are more or less downy, thick walled and often more than 7 cm in length; and the seeds are rounded-rectangular to ellipsoidal in shape (Canada Grains Council, 1972). The full grown plant is usually about 1 to 2 m in height depending on the sub-species, variety, soil and weather conditions.

The fababean is one of the oldest cultivated field crops of Europe. The crop originated from the regions south

of the Caspian Sea and North Africa (Winton, 1935) from where it was apparently brought into Europe. It has been cultivated since the days of the Hebrews and was mentioned in the literature of ancient Greece and Rome. In North America, it appears that the crop has been planted in Mexico and surrounding territories by the Indians since 5000 B.C. (Morgan, 1970). It is not known whether this is the same as the North African stock.

World production of fababeans has fluctuated over the years as a result of certain prejudices such as unreliable yield performance, influx of cheaper and better quality proteins and the beans ability to bind nitrogen to the soil and thus stimulate weed growth (Canada Grains Council, 1972). As a result of the above factors, total production of the fababean in the European Economic Community fell from 528,000 metric tons (tonne=t) in 1969/70 to 450,000 t in 1971/72. In England however, production increased from 103,000 t in 1965/66 to 308,000 t in 1969/70. Africa also increased production from 638,000 t in 1969 to 683,000 t in 1971.

The fababean is a relatively new crop in Canada. The first two varieties (Herz Freya and Klein Thuringer) were introduced into Manitoba in 1969 from West Germany (Evans, 1974). Several other varieties were introduced in 1970. From this stock, three varieties, Ackerperle, Diana and Efordia were licensed in time for planting in the Spring of 1973. Alberta and Saskatchewan first became involved with the fababean in the fall and winter of 1971 respectively. Since

then, the acreage devoted to this crop has increased considerably. Aherne (1974) stated that the acreage of fababeans grown in Western Canada has increased from 2000 acres (810 hectares) in 1972 to 21,000 acres (8,505 hectares) in 1973 with 50,000 acres (20,250 hectares) anticipated for 1974. 10,000 acres (4,050 hectares) was cultivated in Alberta in 1975.

Composition

A comparison of the composition of fababean, soybean meal, barley and cassava is shown in Table 1. The average crude protein content of Canadian grown fababeans in approximately 26 percent with a range of 24 to 30 percent. The lysine content as a percentage of the protein is similar to that of soybean meal and considerably higher than that of barley. Although the sulphur containing amino acids (methionine and cystine) content appears lower than that of soybean meal, Aherne (1974) found that supplementation of fababean-based diets with synthetic methionine generally failed to elicit improved response in pigs. Although the ether extract fraction of fababeans is intermediate between soybean meal, barley and cassava, the fatty acid composition is similar to that of soybean meal and barley. Fababeans contains more than 60% carbohydrate on a dry matter basis. The vitamin and mineral content of fababeans compare well with other vegetable protein sources.

TABLE 1

AVERAGE NUTRIENT CONTENT OF FEEDSTUFFS

USED IN THE EXPERIMENT

(Fababeans, Soybean Meal, Barley and Cassava)

		Fababeans[1]	Soybean Meal[1] (44%)	Barley[1]	Cassava[2]
Dry Matter	%	87.5	89.0	89.0	91.9
Crude Fibre	%	6.7	7.0	5.0	8.3
Ether Extract	%	1.1	0.5	1.9	1.9
Crude Protein	%	25.7	44.0	10.6	2.70
Calcium	%	0.08	0.25	0.10	0.12
Phosphorus	%	0.35	0.60	0.35	0.16
Lysine	%	1.51	2.90	0.50	0.1
Methionine	%	0.18	0.60	0.18	0.04
Digestible Energy kcal/kg		2970	3300	3168	4000

[1] Aherne (1974). (44% crude protein content.)

[2] Thailand cassava pellets, (Hare and Saben, 1974).

Pritchard et al. (1973) found some seasonal and varietal differences in the amount of available carbohydrates in fababeans. They showed that winter-sown varieties provide more available carbohydrates (46 to 48% of the dry matter) than spring-sown varieties (30 to 42%). Bond and Toynbee-Clarke (1968) had earlier found differences in protein content between spring and winter varieties. They showed that spring varieties had consistently higher crude protein content than winter varieties. Eden (1968) also found that spring varieties had a significantly higher crude protein content (average 31.4% on dry matter basis) than winter varieties (26.5%). Winter varieties had a higher crude fiber content (average 9%) than spring varieties (average 8%).

Estimates of D.E. or Metabolisable Energy (M.E.) for fababeans appear to be available only for poultry. Carpenter and Johnson (1968) found that the M.E. values of three varieties of fababeans for chicks were 2.52 to 2.80 kcal/g at 90% dry matter. Waring and Shannon (1969) however found slightly lower values of 2.47 kcal/g and 2.39 kcal/g for spring and winter varieties respectively.

Toxic Factors

It has long been assumed that the fababean would contain toxic components in the form of cyanogenic glycosides like all other Vicia spp. However, as pointed out earlier, small fababeans have only a very tenuous

relationship with other Vicia species. In a survey carried out by the Canada Grains Council (1972) in Austria, England and the Federal Republic of Germany, the non-toxicity of the fababeans was affirmed. Wilson et al. (1972), however, produced in vitro evidence to show the presence of trypsin inhibitor activity (t.i.a.) in field bean meal in chick growth studies. Autoclaving at 110°C for a period of 40 mins. eliminated the t.i.a. They reported that Borchers and Ankerson found no t.i.a. in field beans (fababeans) although in further work, the growth rate of rats was significantly increased from 1.58 to 2.12 g/day when the fababeans were autoclaved at 121°C for 30 mins. Aherne (1974) states that t.i.a. levels in fababeans is only one twenty-fourth that in soybean meal. He concludes from his studies that the presence of t.i.a. in fababeans is of little significance.

Palatability

Fababeans have a somewhat bitter taste due to the presence of 0.34 to 0.50% tannins in the seed (Aherne, 1974). This may therefore lead to reduced feed intake especially when high levels of fababeans are fed initially to livestock.

Fababeans in Swine Diets

Reports in the scientific literature on the use of fababeans in pig rations are rather few. Aherne and McAlease

(1964) carried out three experiments to evaluate field beans (fababeans) as a protein supplement for growing-finishing bacon pigs. In trial one, three levels of fababeans (10, 20 and 30% of the air dry feed) were tested and the digestibility of the fababeans was used as a measure of utilization by 65-day-old pigs. Although there was a wide variation between the crude protein content of the rations used, they showed that the crude protein digestibility for the beans was 80% at the three levels of inclusion. In trial two, they fed pigs from 40-120 lb (18-55 kg) on rations containing 10, 20 and 30% fababeans with and without methionine supplementation. The results showed that ADG were not significantly different for the three levels of fababeans with or without methionine. However, EFC was poorer for the methionine supplemented diets. In trial three, the same three levels of fababeans were used but the diets were unsupplemented with methionine. The rations were fed to finishing bacon pigs from 120-200 pounds (55-91 kilograms). They obtained good growth rates and EFC but in all cases, the control ration was superior to the fababean-supplemented rations. They concluded that fababeans can be substituted for other proteins in finishing rations at amounts not exceeding 20 percent.

Clarke (1970) reported that Luscombe compared the effects of partial and complete replacement of soybean meal by fababeans in rations fed to pigs from 32-91 kg live weight. He observed no significant differences between diets in ADG and EFC. There were also no beneficial effects from

methionine supplementation. Clarke also reported that Clausen and Hansen in Denmark fed bacon pigs diets containing up to 30% fababeans. Increasing the level of fababeans in the diet had no effect on the taste or consistency of the meat from the pig carcasses.

In feeding trials at the Harper Adams College, England (Anonymous, 1972) three levels of fababeans (0, 10 and 20%) were fed to pigs during the growing period from 70-120 lb (32-55 kg) live weight and 0, 15 and 30% during finishing from 120-200 pounds (55-91 kg). They observed a depression of weight gain at a level of 20% fababeans during the growing period (0.59, 0.58 and 0.53 kg/day). Fababean inclusion also adversely affected EFC at both 10 and 20% levels during the growing period. In another trial, they fed a ration containing 20% fababean meal from 50-120 lb (23-55 kg) live weight and 30% fababean meal to 200 lb (91 kg) live weight. The diets were supplemented with methionine and cystine. They observed some improvement from methionine supplementation and concluded that the growth depressing effects of fababeans observed in the first experiment might be due in part to methionine deficiency.

Canada Grains Council (1972) referred to a series of feeding trials in Germany which proved that fababeans are an excellent protein source and capable of fully replacing soybean meal in pig diets. They cautioned however that some animal protein must be used in the ration in order to maintain a proper balance of amino acids. Feeding trials in Bavaria where pigs were fed diets containing up to 50%

fababeans without adverse consequences were also reported.

Stothers (1974) fed up to 30-34% fababeans to growing and finishing pigs weighing 80 lb (36 kg) and over. The average daily FI, ADG and EFC were slightly lower than in the barley-soybean diets but carcass quality was similar. When fed to pigs 50 lb (23 kg) initial weight, 20% less feed was consumed, gains were 20% lower and EFC was 10% poorer than for pigs on a barley-soybean meal diet. He also fed a 50:50 barley-heated fababeans (autoclaved for 20 min.) and unheated fababeans starter ration with or without methionine to pigs weighing 30 pounds (14 kg). The results showed that heat treatment and methionine supplementation had an additive effect in improving performance. The data also indicated that methionine supplementation improved FI but impaired EFC.

Aherne (1975) fed different levels of fababeans (0, 15, 10, 25 and 30%) to pigs from 16.5 up to 40 kg live weight. In two other experiments, he fed diets containing 25% fababeans, autoclaved for 0, 30 or 60 min. and 0, 15, 30, 45 or 60 mins. at 121°C to pigs averaging 17 kg live weight. His results confirmed earlier recommendations that fababeans should not exceed 20% of the diet for growing pigs. He did not observe any significant advantage in heating fababeans before feeding.

Bowland *et al*. (1975) fed several combinations (75/25, 50/50, 25/75, 50/50) of FB, Rapeseed meal (RSM) and SBM to pigs from 6.6 kg to market. Their results indicated that there were no significant differences in daily FI, ADG and

EFC between the treatments throughout the feeding period. They concluded that the replacement of SBM by ground unprocessed fababeans or RSM or 50/50 combinations of these supplements will not significantly depress performance in starting, growing or finishing pigs.

Sarwar and Bowland (1976) fed two levels of unprocessed fababeans (10 and 20%) to 6.5 kg live weight pigs for 6 weeks. Their results suggest that 20% unprocessed fababeans can be fed to young pigs without any adverse effects.

The summary of the results above suggests that fababeans can be satisfactorily included in growing rations at levels of up to 15-20% and in finishing rations at up to 30-50 percent.

B. Soybean Meal

Soybean Meal as a Protein Source

Soybean meal (Glycine max) is generally accepted as one of the best plant protein sources and as a standard of quality for protein supplements because of its high protein content, amino acid balance and the uniformity of the processed meal.

Soybean originated from China where it was recognized as an essential food crop before 2,838 B.C. (Feree, 1929). It was introduced from China to neighbouring countries and other parts of the world during the Christian era. The soybean plant was originally cultivated mainly for its oil

but the by-product, after extraction of the oil, has been found to be very valuable as a protein supplement for all classes of livestock.

The United States at present produces about 60% of the total world production of soybeans. China produces about 21 percent. Of the total world production of 56.8 million t in 1974, the United States produced about 33.6 million and China 11.9 million t (F.A.O., 1974). American exports of soybeans/soybean meal has increased steadily over the years.

There is limited soybean production in Canada, mostly in Ontario. In 1974 Canada produced approximately 300,000 t of soybeans, about 0.5% of the world total. Western Canada relies almost entirely on the United States for its supplies of soybean meal.

Composition

The average chemical composition of soybean meal is shown in Table 1.

The protein content is relatively higher than in most plant proteins. Soybean meal products with 44%, 45%, 48.5% and 50% protein, are available. The protein content in most cases depends on the variety of seed, processing method used and crude fiber content. The lysine content is quite high but the methionine level is rather low. The amino acid profile is better than that of other readily available plant proteins.

The D.E. value of SBM is higher than that of FB. Waring

and Shannon (1969) using colostomized laying hens found that the average M.E. value of SBM was 2.57 kcal/gram.

Bowland (1974) in two separate experiments with pigs found that the D.E. for SBM (44%) was 3179 and 3106 kcal/kg and M.E. was 3087 and 3003 kcal/kilogram.

Toxic Factors

It has been known for a long time that raw soybeans, despite their high protein and fat content, contain factors which result in lower feeding value when fed to monogastric animals (Osborne and Mendel, 1919). It was also known that cooking brings this value for soybeans close to that of meat and milk (Liener, 1958). Several reports now indicate that many factors are involved. Some of the factors which have been implicated are trypsin inhibitors, haemaglutinin and pancreatic hypertrophy factor (Kwong and Barnes, 1963; Muelenaere, 1964; Young, 1970). Rachis (1965) attributes between 30 and 60% of the decrease in growth rate and protein efficiency respectively and nearly all of the pancreatic hypertrophy in rats fed raw soybean meal to trypsin inhibitors. Growth depression by ingestion of trypsin inhibitors has been attributed to endogenous loss of essential amino acids in the enzymes secreted by the hyperactive pancreas in response to the stimulatory effects of the inhibitors (Lyman and Lepkovsky, 1957). Liberation of a hormone-like factor by trypsin inhibitor has been suggested as a mechanism for stimulation of pancreatic

secretion (Khayambashi and Lyman, 1969; Melmed and Bouchier, 1969). Rachis (1965) was able to account for only a part of the anti-growth effects of raw soybean meal in terms of trypsin inhibitors and haemaglutinins. Consequently, there still appears to be some unidentified anti-growth factors in raw soybean meal.

Rachis (1966) stated that all the trypsin inhibitors in raw soybean meal are readily inactivated by heat steaming at 100°C for only 15 min or atmospheric pressure steaming for 20 min. This inactivation also takes place during the processing of soybeans to produce soybean meal. Methods used in processing soybeans and overheating can however markedly affect the nutritive value of the resulting meals (Reisen et al., 1947; Clandinin, 1949). Clandidin and Robblee (1952) indicated that the decreased nutritive value of overheated meal was associated with the decreased liberation of essential amino acids.

Soybean Meal in Swine Rations

Since the acceptance of SBM as a very good protein supplement for livestock feeding by nutritionists, very little further work has been done re-evaluating this protein source. It is now used in most practical feeding experiments as a standard control. As a result, there are very few recent references in the literature dealing specifically with SBM as a protein source for swine.

SBM is a very good protein supplement for growing-

finishing pigs. Hays et al. (1959) compared dried skim milk (DSM) and SBM in pig starter rations. He found that ADG and EFC were significantly better on the DSM diet than on the SBM diet. Supplementation of the SBM diet with 0.05% DL-methionine improved the performance of the pigs.

Combs et al. (1959) also compared DSM, SBM and FM in rations for 2- to 8-week-old pigs. The results indicated that DSM was superior to either SBM or FM. In another experiment, he compared SBM and peanut meal (PNM) and found that the SBM diet gave significantly higher ADG and EFC than PNM. Bowland and Orok (1973) reported that 50 to 100% substitution of PNM for SBM in pig diets reduced ADG but EFC was only poorer at the 100% level of substitution.

Young and Smith (1973) found that pigs fed cooked soybeans had a similar performance to those fed soybean meal. Performance of the pigs fed cooked soybeans was superior to that of pigs fed raw soybeans.

All available literature suggests that SBM can be included in cereal-based pig rations at levels required to meet the protein and amino acid requirements of the animal. This is why SBM is generally used as a standard control in practical pig feeding experiments.

Cassava as an Energy Source

History

The tropical root crop, cassava, is called by various

common names in different parts of the world. All apply to the one species Manihot esculenta Crantz. The names most frequently encountered are: cassava in English-speaking tropical areas; yuca in Spanish-speaking areas; mandioca or macacheira in Brazil; manioc among French-speaking peoples. Tapioca, one of the products manufactured from the roots is sometimes used as a common name. In this report, cassava, the most common English name, will be used throughout.

Cassava is thought to have originated from Brazil, from where it spread to other parts of Latin America and in post-Columbian times, to other parts of the tropics (Smith, 1968).

Manihot esculenta Crantz is the only edible cultivated species of the genus Manihot, comprising about 125 species. The genus belongs to the family Euphorbiaceae along with other economically important species such as para rubber (Hervea brasiliensis) and castor bean (Ricinus communis).

Cassava is a shrubby perennial plant about 1-4 m tall. The stem is either unbranched, tall and slender or variously branched. The stem is woody, usually with a large pith and therefore quite brittle. The nodes are prominently raised on the stem. The leaves are simple, palmately lobed.

Under cultivation, the plant is propagated vegetatively by stem cutting and adventitious roots radiate from the base of the cutting when planted. During growth, some of the adventitious roots become tuberous with carbohydrate reserves. The shape of the tubers vary from long and slender to globose and can weigh from 1-5 kilograms.

Two groups of cultivars of cassava are known: bitter and sweet. Sweet cassava is grown more for food and livestock while the bitter type which has a higher starch content is cultivated for industrial purposes (Ayres, 1972). Godoy (1940) observed that a sweet variety in one region can become bitter under different conditions of climate and altitude. Bitterness has also been associated with glycoside content (Pereira et al., 1965). Sinha and Nair (1968) however suggested that sugars in the roots influence organoleptic evaluation. On this basis, cassava is considered sweet if it contains less than 50 mg prussic acid (hydrocyanic acid) per kg of tissue and bitter if it contains more than 100 mg/kg (Bolhuis, 1954).

World Production

World cassava production has gradually increased from 62.5 million t in 1955 to 104.9 million t in 1974 (F.A.O., 1974). Nigeria in 1974 produced about 10 million t equivalent to about 9.5% of the world total. The Latin American countries produced about 39% of the world total out of which Brazil alone produced about 33 percent. These figures may not however reflect an accurate production because cassava is still largely grown by subsistence farmers on small scattered holdings, usually with much intercropping and under shifting cultivation (Coursey and Haynes, 1970). The collection and interpretation of actual production statistics is therefore difficult and inaccurate.

In some areas where cassava is predominantly grown, actual production statistics are non-existent. This is because most of the crop is produced as a "backyard" staple for home consumption.

The prominence of cassava as a crop in tropical countries is explained by its ecological adaptability and its suitability to the agricultural conditions prevalent in the cassava belt. Some of the main attributes are:

1. It is easily propagated and is relatively high yielding.
2. It is inexpensive to produce, requires little or no weeding because of its leafy canopy and has no critical planting time.
3. It is a reliable and excellent producer of carbohydrates. Coursey and Haynes (1970) indicated that cassava can produce 250 kcal/ha/day as compared with 176 for rice, 200 for maize, 114 for sorghum and 110 for wheat.
4. Its hydrocyanic acid (HCN) content makes it subject to minimal animal and pest attack.

Importance in World Food Supply

Coursey and Haynes (1970) indicated that cassava may be regarded as the staple food of about 200 million people in the tropics. Cassava contributes to world food supplies in the following ways:

1. The roots are detoxicated and consumed as primary,

secondary or supplementary food; 95% of world production is consumed thus. Several dietary surveys conducted in various parts of the tropics support this view. Culwick (1950) indicated that in the Congo region 27-72% of the total calories consumed were contributed by cassava. In Southern Nigeria, 24.9-55.7% of the diet was composed of cassava (Nicol, 1952). Oyenuga and Opeke (1957) concluded that the entire population of Nigeria could rely on cassava alone to meet 80% of the 2,600 calorie/person/day requirement. Cassava contributed 38-47% of the calories in the diet in Ghana (Gold Coast, 1953). Bailey (1961) indicated that cassava is the primary staple in Java and Madura regions of Indonesia where it contributes about 67% of the calorie intake.

2. The roots are used in livestock feed and the livestock are consumed by humans. Imports of cassava roots for this purpose has increased tremendously over the years.

3. Cassava starch or flour is incorporated into food products consumed by humans, such as sauces, gravies and baby foods. Fortified products such as tapioca, macaroni (consists of cassava flour, wheat flour and peanut flour) have also been made (Balu, 1958). Phillips (1974) stated that cassava in 1970 provided 38% of calories in Africa, 12% in Latin America and 7% in the Far East. He predicted that by 1980,

cassava will continue to provide 37% of calories in Africa, 11% in Latin America and 6% in the Far East. Whether the above forecast will be met will depend on increased cassava production.

Chemical Composition and Nutritive Value

Composition

Cassava roots contain varying amounts of carbohydrates, lipids, proteins, minerals and vitamins depending on the variety, location, environmental conditions, the method of chemical analysis and whether the tubers are peeled or dehydrated. An estimated average composition is 60-65% water, 30-35% carbohydrates, 0.2-0.6% ether extract, 1-2% crude protein and relatively low contents of minerals and vitamins. (See Table 1 for the average composition of dry pellets.) It would appear that a considerable amount of protein is lost in the peel which is generally removed during processing. Considerable variation also exists between the sweet and bitter varieties. Maner (1973) reported a large variation (0.2 - 2.3 percent protein) in his analysis of fifteen cultivars in Colombia.

Carbohydrates

The cassava root contributes mainly carbohydrates (energy) to the diet of humans and animals. Johnson and

Raymond (1965) indicate that 64-72% of the carbohydrates is starch. The two main constistuents of the starch are amylose and amylopectin which make up 99% or more of the dry cassava starch. Recently, Jadot (1968) and Maghuin-Rogister (1968) reported a new dissacharide called "manioca" from cassava flour. Sucrose can be as much as 17% in some sweet cultivars.

The rate of starch deposition in cassava roots was studied by Ketiku and Oyenuga (1972). They indicated that the highest concentration of starch (81%) was observed eight months after planting while that for sugars (5.1%) was attained nine months after planting.

Sreeramamurthy (1945) studied the digestibility of cassava by two enzymes and found values of 48.3% for raw cassava and 77.9% for cooked cassava. Maner (1973) estimated the calorie output per hectare per year of a well managed, improved cassava to be about three times that of rice and maize. One kilo of fresh cassava containing 35% dry matter has a gross energy value of approximately 1225 kcal. Coursey and Haynes (1970) pointed out that grain crops have virtually reached their genetic potential for yield whereas the tropical root crops (cassava) are still virtually untouched. There is therefore a wide scope for substantial improvement.

Lipids

The lipid levels in cassava are quite low (about 0.5

ether extractable material) while most animals should have 1-2% lipids in their diets. The fatty acid profile of cassava lipids is not known.

Protein and Amino Acids

Most of the cassava now being produced has a very low content of nitrogenous substances. The crude protein (N x 6.25) content of the majority of the varieties tested does not exceed 3% (Maner, 1973). A major proportion of the total nitrogen however exists as simple nitrogenous compounds (Sreeramamurthy, 1945). Sreeramamurthy (1945) also found that the digestibility of the crude protein was 48% and is thus comparable to rice protein.

Cassava varieties have been reported to contain higher levels of crude protein than are normally reported. Maner (1973) quoted Beck (1969) who reported an African variety containing up to 9% crude protein. Other varieties may contain up to 2.3% crude protein on wet basis or 7.3% on dry matter basis. Maner and Daniels (1970) indicated that the level of total nitrogen is higher in the peel than in the remaining portion of the root but the internal portion contains more crude protein due to its larger volume. Maner and Daniels (1971) also indicated that the percentage of non-protein-nitrogen is higher in the peel than in the pulp. These results do not agree with those reported by Oyenuga (1955) that 62% of the nitrogen of the crude root was true protein and that 87% of the nitrogen of the peel was true

protein.

The amino acid composition of cassava meal is compared with hybrid corn, Opaque-2 corn and barley in Table 3. The lysine content of cassava appears to be adequate but methionine is low. Cassava is essentially deficient in the sulphur-containing amino acids. Bailey (1961) also indicated that cassava-based diets in Indonesia are deficient in sulphur containing amino acids (methionine, cystine and cysteine). Oshuntokun (1968) explained that both cystine and cysteine are involved in the cyanide detoxication (when the cyanogenic glucoside present in cassava is hydrolysed by linase or acid to produce a thiocynate, cystine and cysteine are used up in the process). Therefore, this may be responsible for the low levels of the sulphur containing amino acids, expecially during excessive detoxication. Methionine-supplementation of cassava-based diets has been shown to significantly improve weight gain and EFC. (Maner, 1973). Hendershott (1972) warned that estimates of total nitrogen in cassava roots will have to be viewed with caution because it is not known whether the breakdown products of cyanogenic glucosides do enhance the total nitrogen content. Nartey (1968) showed that the hydrolytic products of glucosides are incorporated into amino acids for protein synthesis in cassava.

TABLE 2

AMINO ACID[1] CONTENT OF THE PROTEIN IN CASSAVA, CASSAVA MEAL, BARLEY AND CORN

Amino Acid	Cassava[2]	Cassava[3] Llanesa	Nigerian Cassava[4] Meal	Barley[5]	Common[3] Corn	Opaque-2[3] Corn
Arginine	3.7	18.0	10.3	4.7	4.6	6.2
Histidine	1.2	2.3	1.9	2.1	2.9	2.7
Isoleucine	2.0	1.7	1.9	3.8	5.0	3.6
Leucine	2.9	2.0	3.1	7.3	16.0	8.0
Lysine	3.5	2.6	5.0	3.6	2.8	4.0
Methionine	1.0	Trace	0.6	1.6	3.0	4.5
Alanine	4.6	2.6	4.7	4.2	9.4	5.9
Threonine	2.1	6.2	1.9	3.5	3.5	3.3
Phenylalanine	2.3	1.0	2.2	5.5	5.4	3.8
Valine	2.6	1.1	2.5	5.0	7.2	5.6
Tyrosine	1.6	0.6	1.9	2.4	4.9	3.5
Glycine	2.4	0.9	2.2	4.2	4.1	5.3
Glumatic Acid	12.7	5.3	13.1	22.2	20.6	15.2

[1] Expressed as % of protein or g of amino acid/100 g protein.

[2] Close et al. (1953).

[3] Maner, J.H. (1973).

[4] Orok and Bowland (1974).

[5] University of Alberta data (1975).

Minerals and Vitamins

Cassava roots are relatively rich in ascorbic acid and contain significant amounts of thiamine, riboflavin and niacin (Hendershott et al., 1972). Maner (1973) considered the levels of calcium (0.12%), phosphorus (0.16%), sodium (0.06%) and magnesium (0.37%) comparable to levels in most root crops.

Toxic Factors

1. Cyanogenic Glucosides

The cyanogenic glucosides are distributed throughout the cassava plant but the concentration varies greatly between varieties and is influenced by climatic, edaphic and cultural conditions (Oke, 1969). The normal range of cyanogen content is from 15-440 ppm expressed as mg HCN/kg fresh weight but occasional samples as low as 10 mg/kg or over 2000 mg/kg have been reported (Rogers, 1963).

Cassava plants possess two types of cyanogenic glucosides, Linamarin and Lotaustralin (Clapp et al., 1966; Bessett et al., 1969). Nartey (1968) indicated that Linamarin accounts for 93% of the total glucosides and Lotaustralin for 7 percent. The glucosides consist of a chemical combination of a sugar and hydrocyanic acid or prussic acid (HCN) and perhaps other compounds such as an aldehyde or a ketone. For example, Linamarin is composed of HCN, glucose and a ketone. As indicated earlier, cassava is

often described as "bitter" or "sweet" depending on the amount of cyanide present although there is really little correlation between so-called sweetness and cyanide content (Peireira and Pinto, 1962). In general, bitter cassava tends to have a higher cyanide content than sweet cassava (Rogers, 1963a; Nartey, 1973), but there is a great deal of overlapping between the two classes (Coursey, 1973). Coursey (1973) also indicated that in most varieties and under most cultural conditions, the cyanogenic glucoside content is much higher in the peel than in the fleshy part of the tuber. Wood (1965) had reported that the mean value of HCN for the phelloderm (rind) was over ten times that of the remaining tuber. Orok and Bowland (1974) also found a higher concentration of HCN in the peel (0.05%) than in the meal (0.006%).

The cyanogenic glucosides of cassava are accompanied in the plant tissue by a hydrolytic enzyme, Linamarase (often called Linase). De Bruijn (1973) showed that the activity of the enzyme is highest in the young expanding leaves, in the peel of the tuber and lowest in the inner part of the root. In the active, healthy tissue of the growing plant however, enzyme and substrate do not come together. Contact occurs only when the tissues are mechanically damaged or physiological integrity is lost during post harvest deterioration of the tubers or wilting of the leaves. Hydrolysis then takes place and HCN, acetone and glucose are liberated (see Figure 1 for the reaction). Before feeding to livestock and humans, subsequent treatment of cassava such

as fermenting, chopping or drying, activate the hydrolytic process and thereby affect the amount of HCN found (Hill, 1973).

Nature of Toxicity

Couch (1932) indicated that neither the glucoside nor the enzyme present in cassava are poisonous by themselves. The toxicity in cassava and its products is associated primarily with the free HCN that is formed during hydrolysis. The degree of toxicity of cassava roots has been widely discussed and differences in opinion exist. Despite these differences however, it is known that HCN in itself is poisonous.

In animals, the symptoms of acute hydrocyanic acid poisoning are increased rate and depth of respiration, increased pulse rate, no response to stimuli and spasmodic muscular movements (Oke, 1969). Maner (1973) explained that these symptoms of HCN poisoning can be explained on the basis of affinity for metal ions such as copper and iron. HCN combines with haemaglobin to form cyanohaemoglobin and thus reduces the oxygen carrying ability of the blood. HCN also forms a reversible combination with copper of the cytochrome oxidase and there by inhibits its function as an oxidative enzyme in electron transfer. These chemical abnormalities cause neural depression in the medullary centres leading to respiratory depression and death.

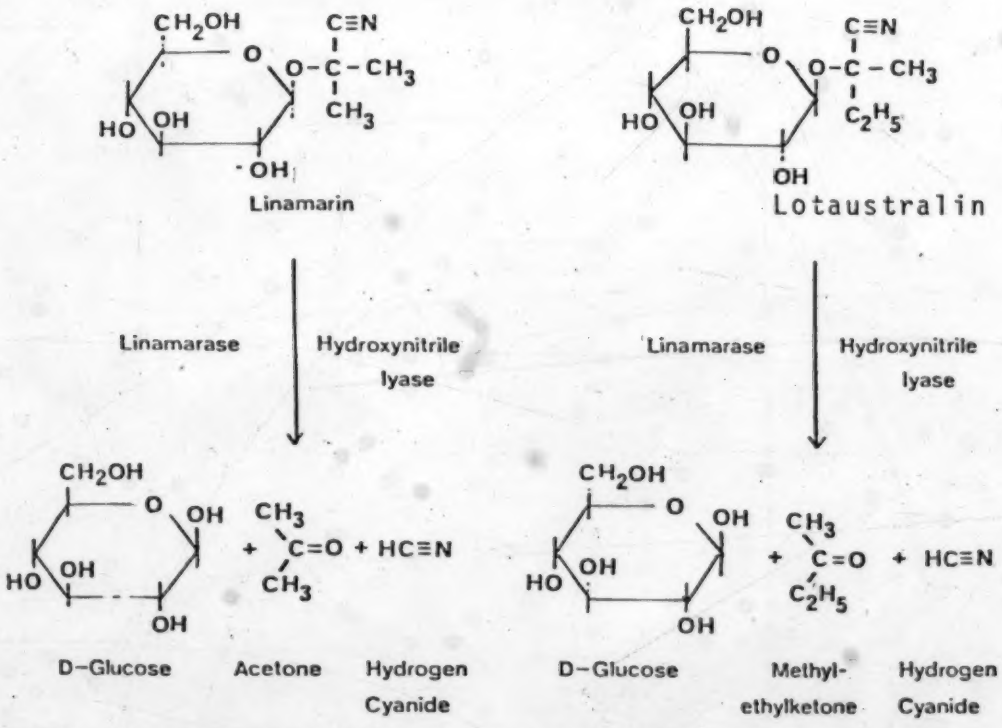

Fig. 1. The structures and hydrolytic products of the cyanogenic glucosides of cassava, linamarin and lotaustralin.

Nartey (1973)

It is also suggested (Maner, 1973; Coursey, 1973) that continued ingestion of small amounts of HCN is more dangerous than acute toxicity. Although these small amounts are not large enough to cause death, they can affect the general health and condition of the subject.

Oshuntokun (1971), Oluwasanmi and Alli (1968) and Ekpechi (1973) indicated that high cassava diets could be the cause of endemic goitre in Nigeria. Ekpechi's results showed that cassava has an adverse effect on the function of the thyroid comparable to that of thionamide giotrogen. Thiocyanate, a detoxication product of cyanide, is a well known goitrogenic substance. Studies on the etiology of human ataxic neuropathy in Nigeria (Oshuntokun et al., 1969) and in Tanzania (Makene and Wilson, 1972) have led to the hypothesis that this condition is caused by chronic exposure to cyanide or cyanogens ingested in cassava. Results obtained with domestic animals on neuropathological effects are not too reliable. Experimental evidence from feeding trials is only available for rats and dogs. Martino (1935) reported that rats fed cassava roots developed neuromuscular symptoms. Experiments with animals also strongly suggest that thiocyanate formed during the detoxication of ingested cyanide interferes with the utilization of iodine for thyroxine production (Ekpechi, 1967).

The possibility of HCN poisoning and the role of thiocyanates as a poisoning agent has been of much interest. Lang (1933a) postulated the existence in the body of a heat-labile enzyme called "Rhodanase" which is responsible for

the reaction of HCN and thiosulfate or colloidal sulphur under anaerobic conditions to produce the detoxication product, thiocyanate. Maner (1973) indicated that the amount of HCN detoxified varies with the species, physical condition, nutrient consumption and other unidentified factors.

Rhodanase is widely distributed in all tissues of the body but the highest concentration is in the liver. Himwich and Saundels (1948) found that the amount of Rhodanase in the liver varies with different animals. From the distribution of the enzyme in the tissues, they calculated that the whole liver of a dog can detoxify about 4015 g cyanide and the skeletal muscles 1743 g cyanide to thiocyanate in 15 min, yet only small doses are required for toxicity. Thiocyanate concentration at least three times that of cyanide is required for the reaction to proceed efficiently. Readily available sulphur is also required for in vivo detoxication.

Subsequent work by Saunders and Himwich (1950) threw more light on the function of Rhodanase. They indicated that Rhodanase forms a loose combination with thiosulphate which breaks down to yield sulphur in a form that can be accepted by the cyanide ion to form thiocyanate.

The Rhodanase system is not the only route of detoxication of HCN to thiocyanate. Meister and Fries (1953) found that 3-mercaptopyruvic acid can provide sulphur as rapidly as thiosulfate for cyanide detoxication. He found that crude extracts of liver converted this compound into

pyruvic acid and free sulphur at pH 7.5-8.5. This was also confirmed by Wood and Fielder (1953) using B-mercaptopyruvic acid and optimum pH of 9.1.

Vitamin B12 has also been postulated to play a direct or indirect role in cyanide detoxication. Kaczka et al. (1950) showed that in the presence of light, vitamin B12 (cyanocobalamin) is converted to vitamin B12a (hydroxycobalamin) which can react with cyanide to regenerate vitamin B12. The cyanide is incorporated into the 1-carbon metabolic pool probably in the form of formate. It therefore appears that the differences in toxicity reported for cyanide may be due to presence or absence of substances such as methionine, cysteine, sulphur, vitamin B12, iodine, and other elements like copper and iron.

Wokes and Pikard (1955) explained the cyanide detoxication in vivo process. When cyanide is ingested, both vitamin B12 and Rhodanase compete for it. Some is detoxified by Rhodanase through the help of sulphur donors (sulphur containing amino acids, etc.) to thiocyanate which is excreted. Some of the cyanide combines with hydroxycobalamin to form cyanocobalamin which then carries out various metabolic functions. Vitamin B12 can lose some of the cyanide to supply the 1-carbon fragment for the synthesis of important compounds such as choline or other components containing methyl groups.

The detoxication mechanisms in the body discussed above can therefore sufficiently cope with ingestion of small amounts of cyanide formed during metabolism (Oke, 1973). As

indicated earlier however (Hill, 1973), the thiocyanate formed during the detoxication of ingested cyanide can interfere with iodine utilization for thyroxine production.

Cyanide Toxicity in Domestic Animals

Although Oke (1969) showed the basic role of hydrocyanic acid (HCN) in nutrition, there is no literature dealing specifically with cyanide toxicity in domestic animals. Acute poisoning from the consumption of cyanogenic plants is more of a risk to grazing animals than to poultry or swine which are, to a large degree, fed formulated diets.

Feeding trials with cattle or sheep using a variety of plants with cyanogenic potential have failed in general to clearly indicate chronic toxicity. Assis et al. (1962) and Mathur et al. (1969) fed cassava in various forms, including tapioca meal and chopped roots and could not produce obvious ill effects. Oyenuga and Amazigo (1957) however reported that the levels of HCN (0.034-0.1121%) they found in six varieties of cassava would be toxic to livestock. Nichols (1957) stated that 0.06g had been found to be the smallest lethal dose to adult animals.

Results with swine are variable. Mondonedo (1928), Mondonedo and Allonte (1931), Woodman et al. (1931), Alba (1937) and others have fed large amounts of cassava in various forms to swine with satisfactory results and no evidence of HCN toxicity. Peixoto (1965) and Velloso et al. (1965-66) however found reduced gains as the level of

cassava in swine diets was increased. Workers at the Centre for Tropical Agriculture, Colombia (Maner, 1973) have investigated the use of fresh, dried and finely ground and ensiled cassava roots for growing and finishing swine and for gestation and lactation. They found that in general, cassava was a satisfactory replacement for corn in practical diets. However, they found depressed growth with the dried and finely ground cassava when the level of cassava in the diet was 60-70 percent. There was no indication that cassava was contributing a toxic level of HCN to the diets.

It could however be argued that most of the publications referred to above did not specifically test the relationship of cassava on performance to the intake of hydrocyanic glucosides or HCN. No information was either obtained or recorded on the amount of HCN present in the diet. Neither did they evaluate the effects of HCN ingestion on thyroid tissue.

Maner and Gomez (1973) fed fresh chopped cassava containing 150 mg HCN/kg, or sun-dried cassava meal containing 5 mg HCN/kg to growing rats for a period of four months to measure the effect of HCN on performance. The results showed that the rats fed a protein supplement and fresh cassava gained weight significantly faster than the others. The average excretion of thiocyanate in urine was proportional to the quantity of HCN consumed. An autopsy showed no difference in thyroid size in any of the rats on different treatments. The question thus remains: does chronic HCN toxicity from the ingestion of cyanogenic plants

like cassava occur in domestic animals, and if so what is the nature? Better controlled experiments are needed to satisfactorily answer this question. Maner and Gomez (1973) concluded that cyanide is without measureable effect on goitre production or nerve degeneration in the presence of adequate methionine and iodine. Hendershott et al. (1972) also think that the use of sweet cultivars and proper treatment to liberate the HCN should be adequate to insure safe feeding of cassava.

Goitrogens and Thyroid Function

As mentioned above, cassava contains some goitrogenic substances in the form of cyanogenic glucosides. Hill (1973) indicated that the thiocyanates formed during the detoxication of ingested cyanide can interfere with iodine utilization for thyroid hormones (T3 and T4) production.

The thyroid gland has a remarkable capacity to absorb iodine from the circulating blood so that it contains some 20% of the total iodine present in the body. This iodine is used for the synthesis of two major hormones, thyroxine (T4) and triiodothyronine (T3). Iodine is provided from the ingested food and water. The iodine is absorbed as iodide and circulates in the blood as such. The synthesis of hormones by the thyroid gland is brought about by a sequence of actions. Inorganic iodide is trapped by active transport (iodide pump) which is energy dependent and the trapped iodide is very readily bound to proteins within the colloid.

This iodide pump can be depressed by thiocyanate and sodium perchlorate. The iodide ions are then oxidized to free iodine by the action of pyroxidase. The iodine is taken up by tyrosine to form mono-iodotyrosine (MIT) and then di-iodotyrosine (DIT). By coupling of one or two molecules of DIT, with the elimination of alanine, T3 or T4 are formed. These hormones are bound to highly specialized storage proteins called thyroglobulin and released into the blood stream as needed when acted upon by a protease.

The main function of these hormones appears to be the stimulation of cellular oxidation and the maintenance of normal level of metabolic activity in virtually all tissues of the body (Wolf and Wolf, 1964). Moderate concentrations of thyroid hormones also have an anabolic effect, causing an increase in RNA and protein synthesis. High or low concentrations result in a state known as hyperthyroidism or hypothyroidism. Since the two main factors which determine the amount of hormones produced by the thyroid gland are, the thyrotropic hormones and the availability of iodine to the thyroid gland (Keele and Neil, 1966), thyroid deficiency can arise from an inadequate intake of iodine or from the presence of substances (goitrogens) which interfere with thyroid hormone synthesis. In either case, the blood thyroxine level is subnormal, thyrotrophin secretion is increased and the thyroid gland enlarges with hyperplasia (simple goitre).

T3 and T4 as a Measure of Thyroid Status

It was long recognized that thyroxine (T4) constitutes about 90% of the organic iodine-containing substances in the blood (Oppenheimer, 1968; Robbins and Rall, 1969). Twelve years after the initial demonstration of T4 in plasma, Gross and Pitt-Rivers (1952), identified triiodothyronine (T3) as the second most important circulating iodoamino acid. Taurog et al. (1956), showed that T3 like T4, is a normal thyroidal secretory product. Hollander and Shenkman (1972) indicated that T3 is more readily metabolized and occurs in lower concentration in the blood than T4. Despite its low level in serum relative to T4, it has been estimated that T3 contributes a major portion of the caloric potency of thyroid hormones (Robbins and Rall, 1967). Gross and Pitt (1952) suggested that T3 is the active thyroid hormone and that T4 serves merely as a precussor or prohormone. Recent development of radioimmunological assays for direct determination of T3 and T4 have helped to overcome the early methodologic problems. The normal concentration of T3 in human plasma is reported to be approximately 0.10 to 0.15 ug/100 ml (100 to 150 ng/100 ml) compared with T4 which is 4.5 to 10.5 ug/100 ml. Sarwar (1976) found T4 values for pigs to be 1.7 to 3.4 ug/100 ml.

While iodine deprivation might result in subnormal levels of T4 in the blood, it leads to a high serum T3 level in animals and man (Greer et al., 1968). They explained that "preferential" synthesis and secretion of T3 occurs because

T3 possess about four times the potency of T4 per molecule and contains only 75% as much iodine. Thus in the face of iodine deficiency, it is possible to obtain a 6-fold increase in hormonal effect from the same number of iodine atoms by secreting T3 rather than T4. Because of the marked reduction in thyroid iodine content during severe iodine deficiency however, it would be expected that the actual quantity of T3 secreted would be very low and probably inadequate to maintain a euthyroid state.

Hollander (1970) suggested that the relative hypersecretion of T3 may represent an important homeostatic mechanism in the face of inadequate iodine substrate. Hollander also reported that in all the cases of conventional hyperthyroidism he had studied in humans, the T3 levels were invariably elevated. The excessive secretion of T3 rather than T4 is now being referred to as T3 toxicosis (thyrotoxicosis). Hollander et al. (1971) also observed that hyperthyroid patients may pass through a stage of T3 toxicosis before developing the usual form of thyrotoxicosis.

It is thus becoming apparent that T3 and T4 levels are probably the best way of determining thyroid status (Howorth and Maclagan, 1969; Hollander and Shenkman, 1972). This is why these parameters were measured in the experiments reported herein.

2. Aflotoxicity

Cassava has been incriminated in the problems of

aflotoxicity since it appears to be an excellent growth medium for Aspergillus flavus. Samples of cassava flour from Brazil have been shown to contain high levels of aflotoxins and were at one time thought to be responsible for Black Fever in children of the upper Amazon (Boshell, 1968). Studies with cassava starch in Thailand and Hong Kong by Shank et al. (1972) and fermented cassava in Dahomey by Toury and Giorgi (1966) have shown the presence of aflotoxins. In Uganda, Serck-Hanson (1970) provided circumstantial evidence to show that highly contaminated cassava samples may be involved in a documented poisoning episode. Nestel (1974) concluded however that because of the varied ways cassava is handled after harvest, there appears little evidence that aflotoxins present in cassava will present a significant problem.

Utilization of Cassava as a Livestock Feed

The demand for cassava as an ingredient in animal feed has increased over the years. Although world production figures for cassava roots are well documented (F.A.O., 1970, 1972, 1974) the quantity used for animal feed purposes is not well established. Imports of cassava for animal feeding into Western Europe have increased over the years, especially since the development of the European Economic Community's Common Agricultural Policy (Phillips, 1974). The imports of cassava into the E.E.C. has increased from 884,000 t in 1966 to 1,900,000 t in 1974 (Phillips, 1974).

Although Germany alone imported 79.4% of the total in 1966, they only imported about 22% of the 1973 figures. Netherlands has within the same period increased their imports from 96,000 to 700,000 t. In Germany, cassava makes up about 40% of pig diets while in the Netherlands, about 7.5-15% cassava is used for growing-finishing diets.

Types of Cassava Products Used in Animals Feeds

Various forms of cassava roots and products are used in animals feeds. The most common ones are chips, broken roots, pellets, slices and meals.

1. Chips

Cassava chips are the most common form used in the animals feed industry. The standards set are that the chips must contain a maximum of 13-14% moisture, 5-6% crude fibre, 3-5% ash and a minimum of 70% starch. No standard is usually placed on protein content. The size of chips varies but the length should not be more than 4-5 cm because of the tendency for long chips to jam mixing equipment. The chips should consist of roots which should be well peeled, washed and dried. The quality of chips however still varies depending on the source.

2. Broken Roots

These are similar to chips but usually longer.

3. Pellets

The pellet size is usually 1 cm in diameter and 2 cm in length. Pellets are more expensive than chips but are easier to handle; freight rates are lower probably because of less space requirement; and the quality of the product is more uniform. The use of pellets is becoming popular because of the reasons given above.

4. Cassava Meal

This is the residue of roots and chips after processing in manufacture of starch. The meal still contains as much as 55-65% starch but the quality is inferior to chips or pellets due to more contamination.

Cassava in Swine Feeding

Studies to evaluate cassava roots as an energy source for pigs have been reported in the literature since 1900 (Tracy, 1903; Connor, 1907 (cited in Hendershott et al., 1972); Mondonedo, 1928; Woodman et al., 1931; Alba, 1937; Asico, 1941; Sreeramamurthy, 1945; Oyenuga and Opeke, 1957; Modebe, 1963; Peixoto, 1965; Maner, 1973). Most of the above work involved comparing diets containing cassava with diets containing other roots, tubers or cereal grains. Hendershott et al. (1972) quoted Tracey (1903) reporting that many farmers used cassava exclusively during the finishing period. The pigs ate it greedily and preferred it to corn. A summary of the results of studies between 1927 and 1941 by

Maner showed that the maximum satisfactory level of inclusion of cassava for growing and finishing pigs was 40 percent. In most of the cases, the levels of production and feed efficiency were low. Even the results obtained from the controlled experiments were low when judged by our present knowledge and advances in nutritional research.

Feeding Experiments

Mondonedo (1928) compared corn and cassava (20% of diet) using 8-month-old pigs for a 75 day feeding period. The results showed that the pigs fed the diet containing cassava gained 8% faster, ate 9% more feed and required 9% less feed per unit gain than those receiving the corn diet. Feed cost per unit gain was 11% less with the cassava diet but the carcasses were apparently superior on the corn diet.

Asico (1941) used a similar method to that of Mondonedo to compare cassava and corn. He used young weanling pigs and fed them for 210 days divided into three 70-day periods. On the basis of ADG, his results showed that the cassava diet was only 90% as efficient as the corn diet and 95% as efficient on the basis of EFC. He concluded that "gaplek meal" was a good substitute for corn in rations for growing pigs if the price was 95% that of corn.

Oyenuga and Opeke (1957) utilized 40 and 55% fresh cassava for growing and finishing pigs respectively and compared these levels of cassava with guinea corn (sorghum). The fresh cassava was fed either raw or cooked along with

supplements supplying protein, energy and minerals. The pigs were hand-fed thrice a day in order to equalize nutrient intake of cassava-fed animals and control animals. The effects of this hand feeding is not known. They concluded that cassava was equal to sorghum in feeding value and that raw cassava was highly palatable and equal to cooked cassava.

Later, at the same station, Modebe (1963) replaced sorghum or maize with dried cassava at 32, 37 and 40% of the diet for pigs weighing 23-26, 37-55, 55-75 kg respectively. Another group (treatment 2), received dried cassava at 42, 47 and 50% of the diet. The pigs fed the lower levels of cassava meal (32, 37 and 40%) grew at a rate that was not significantly different from that of the control (0.491 vs. 0.482 kg/day) or from that of the higher levels of cassava meal (0.491 vs. 0.473 kg/day). Feed conversion was about the same for treatments 1 and 2 but pigs fed the higher levels of cassava required slightly more (3%) feed per unit gain. The cassava-fed pigs had a lower carcass grade but feeding cost per unit gain was lower for the cassava diet. Modebe found that a level of up to 50 to 55% of the diet can be supplied by either fresh or dried cassava.

Mejia (1960) cited by Maner (1973) used 20 and 40% sun-dried cassava to replace similar quantities of corn in rations for growing-finishing pigs. His results indicated that cassava has an available energy value similar, but not necessarily superior, to that of corn.

Aumaitre (1969) cited by Maner compared dried cassava

meal and corn, wheat and barley and decorticated oats for baby pigs between the ages of 5 and 9 weeks. The cassava diet gave maximum performance (416 g/day) as compared with barley, oats, corn and wheat (386, 380, 354 and 360 g/day). The improvement due to cassava substitution was reported to be due to a reduction in the incidence of diarrhea observed in the pigs. The digestibility results showed that wheat, barley, corn and decorticated oats had DE values of 3973, 3955, 4046 and 4024 kcal/kg respectively, comparable to that of cassava meal (4185 kcal/kg).

Shimada (1970) also cited by Maner used 0, 22, 44 and 66% sun-dried cassava meal to replace corn in diets for pigs between 30 and 90 kg. Although there were insufficient pigs for valid statistical analysis, the results generally indicated that up to 44% cassava meal can be used to replace corn without causing a reduction in overall performance. Cassava at a level of 66% caused both reduced ADG and poorer EFC.

The most recent and extensive work with cassava in swine feeding has been conducted in Colombia by Maner (1973). The studies involved the use of cassava meal, fresh cassava and cassava silage. In experiments 1 and 2, the practice of feeding raw cassava and a protein supplement free choice was compared with a corn-based completely mixed diet. The feeding of protein supplement with cassava was tested in two ways. In one case, both the raw chopped cassava and supplement were fed ad libitum. In another, the raw chopped cassava was fed ad libitum but the protein

supplement was fed daily in sufficient quantities to supply minimal daily requirements. The results from both experiments indicated that pigs fed the supplement ad libitum consumed excessive quantities of protein supplement and balanced their diet at nearly 25% crude protein. Rate of gain was similar in both experiments except that the pigs fed raw cassava free-choice and a controlled quantity of protein supplement gained slightly slower. EFC was improved with the cassava and free choice feeding of supplement. It may be that this improvement was not due to cassava per se.

In experiment 3, cassava was offered ad libitum and two basic protein supplements, cottonseed meal (CSM) and SBM, with two levels of vitamin-trace mineral supplementation, were compared. The results showed consistently that there was no advantage in adding higher than recommended levels of vitamins and trace minerals. The use of CSM at a 25% level of supplementation for soybean meal appeared to be acceptable but feed required per unit gain appeared to increase with CSM as a supplement.

It was observed that the pig does a fairly acceptable job of balancing his diet when offered fresh, chopped cassava and protein supplement free choice. Limiting the protein supplement consumed per day to a level calculated to supply 10% more than the National Research Council's requirements did not result in an increase in daily cassava consumption.

One problem with the three trials was the low consumption of cassava at the start of the trials by young

pigs. If supplement was available free choice, they readily ate the supplement. In general however, the daily voluntary consumption of wet cassava increased progressively from weaning to market weight while the daily voluntary consumption of protein supplement remained almost constant throughout the entire period.

In experiment 4, dried cassava was also fed free-choice with other protein supplements apart from SBM and CSM in order to broaden the application of the data over a wider geographical area. The protein sources used were SBM, meat meal (MM), CSM, and combinations of MM-blood meal (BM); MM, BM and CSM; fish-meal and CSM. In general, reasonably good performance was achieved with SBM, MM, BM and CSM or FM. Rate of gain was inferior with CSM alone. Pigs in all treatments over-consumed protein during the entire experimental period.

In experiment 5, dried cassava meal was incorporated into balanced diets at 33, 66 and 100% of the corn in 16% crude protein diets, in order to measure its energy value as a substitute for corn in growing-finishing pig diets. A factorial design was used and the other variable was 0 or 10% cane molasses to evaluate its effects on reducing dustiness (especially in 100% cassava meal) and improving palatability of the diets. The results showed that each increase in level of cassava caused a corresponding decrease in ADG with or without molasses. The addition of molasses caused an increase in FI by 13% and increased ADG by 10 percent.

Maner also fed cassava silage made from fresh roots or a combination of the whole plant (roots, stalks and leaves). He fed the cassava root silage and protein supplement; cassava root, leaf and stalk silage plus supplement, and fresh chopped cassava plus protein supplement free choice to three different treatment groups. Pigs receiving the root silage gained slightly faster and consumed less feed than those receiving fresh cassava and supplement. He concluded that root silage appears to be a good alternative way to feed cassava. He suggested that the roots and the leaves be ensiled for pigs but that the stalks should not be included.

Orok and Bowland (1974) fed three levels of Nigerian cassava meal (30, 40 and 50%) to rats. Their results showed that at these levels of substitution, the performance of the weanling rats was equal to that obtained with a corn-soybean meal diet.

Feeding trials at the University of British Columbia by Bragg and Kitts (1975) indicated that 5, 10 or 20% dietary cassava is an excellent energy source for starting broiler chicks. They also showed that 40% dietary cassava can be successfully fed to growing and fattening steers.

There therefore appears to be adequate evidence to conclude that cassava can be used in swine feeding. Most authors, however, recommend that it should not be used as the only energy source in the diet. Cassava silage also has a great potential as a livestock feed but the silage should be the roots alone or the roots and leaves. Some other source of dry matter could also be mixed with silage to

increase the energy content, and reduce the loss of nutrients through drainage.

Experimental results show that levels of cassava varying from 10 to 50% of the diet can be fed to pigs. The diets however have to be well balanced in amino acids, minerals and vitamins. Palatability is not a serious problem because the roots are nearly odourless and have a pleasant taste. Although Maner (1973) had some initial palatability problems with very young pigs, feed consumption later increased to a satisfactory level.

The use of cassava in livestock feed is restricted in many countries. These regulations and guidelines were established to protect livestock from potential toxicity at high dietary levels of cassava. Other regulations are related to the low protein content of cassava. In Belgium, the maximum level allowed is 5% of the diet for swine. In Germany and the Netherlands, the maximum level for growing-finishing pigs is 40 percent. In Canada, the suggested levels in swine rations are 10-40 percent (Hare and Associates, 1973; Hare and Saben, 1974).

Despite the limitations highlighted in this review, cassava has a very high potential in swine feeding. Jones (1959) summed up this potential in his book "Manioc in Africa" when he stated that "perhaps the most promising way to take advantage of the low cost and great productivity of manioc is by feeding it to livestock."

EXPERIMENTAL PROCEDURE

Objectives

The objectives of the study were:

1. To assess the nutritive value of FB (*Vicia faba* L. *minor*) as a sole protein supplement or in 50:50 combination with solvent extracted SBM for growing-finishing pigs.

2. To evaluate the effects of feeding a 16% level of dietary protein, supplemented or not supplemented with L-lysine and DL-methionine throughout the starting to finishing periods on the performance of pigs.

3. To assess the nutritive value of pressure processed cassava meal at three levels of supplementation (0, 20, 40% of the diet) for starting pigs.

4. To assess the effects of feeding cassava meal on thyroid function using T3 and T4 levels in the plasma as a measure of thyroid status.

Animals and Housing

One hundred and twenty pigs farrowed at The University of Alberta Edmonton Research Station were used in this study. Their pre-weaning management followed the standard practice for Alberta outlined by Aherne *et al*. (1974). After weaning and before allotment on the experiment, the piglets had access to creep feed and water ad libitum. The pigs were a cross between Yorkshire and Lacombe-Yorkshire. On April 23rd and July 22nd, 1975 respectively, sixty pigs equalized as to sex and weight were allotted to fifteen dietary

treatments, giving two groups in time. There were thus 4 pigs per treatment (2 barrows and 2 gilts) each time or a total of 8 pigs per treatment. Pigs in replicate 1 were allotted at an average age of 26 days and an average weight of 5.85 kg (range 4.4-7.4 kg). Those on replicate 2 were allotted at an average age of 32 days and an average weight of 5.98 kg (range 4.7-9.0 kg).

All pigs were housed in an experimental barn thermostatically maintained at a temperature of 21-22°C. The floors were concrete. During the growing phase, there were two pigs per pen (1 barrow and 1 gilt). During the finishing period (beginning 9 wk after the experiment started), the pigs were moved to a separate barn where they were kept 4 pigs per pen.

Pen size was 0.6 m x 1.2 m during the starter phase and 1.4 m x 3.95 m during the finishing phase.

Experimental Diets and Design

The composition of the 15 diets fed during the growing and finishing phases is shown in Table 3. Diets 1-9 were formulated to contain approximately 16% (N x 6.25) crude protein, 3,300 kcal DE/kg 0.70% calcium and 0.55% phosphorus. Supplemental L-lysine and DL-methionine were added to diets 10-15 to raise the levels of these amino acids in these diets to approximately the same levels as in the 16% protein diets (1-9). The protein supplement in diets 1-3 was supplied entirely by solvent extracted SBM. FB was the sole protein supplement in diets 7, 8, 9, 13, 14 and 15.

Diets 4-6 and 10-12 were a mixture of SBM and FB. The FB were Alberta grown.

Cassava was substituted for barley at levels of 20% and 40% respectively in diets 2 and 3; 5 and 6; 8 and 9; 11 and 12; and 14 and 15. The cassava was made from the whole root, mechanically peeled, pressure processed and imported from Thailand (Saben, personal communication).

The allotment of pigs on experimental diets during the growing and finishing phases is shown in Table 4. The pigs were kept on the 15 dietary treatments during the starting phase (week 1-9). At the end of the 9th week, they were moved on to appropriate no cassava treatments 1, 4, 7, 10 and 13 (4 pigs/pen; 12 pigs/treatment in each of two time periods) until they reached market weight (85 kg).

Water was provided ad libitum by means of automatic fountains installed in each pen. Feed was also provided ad libitum in self-feeders throughout the duration of the experiment.

Growth Studies

Animals were individually weighed every Wednesday throughout the experimental period. Feed intake during each weekly period was also recorded. Pigs were slaughtered when they reached a minimum of 85 kg live weight. In each pen, the last pig, regardless of weight was slaughtered when the third pig reached slaughter weight. This criterion could not be strictly adhered to in both replicates because the pigs on treatment 7 were growing slowly. A deadline was therefore

set for final shipment of pigs. Standard carcass valuation (Grade Index) and Record of Performance indexes were determined (C.D.A., 1969). Details of the Grading and R.O.P. systems used are shown in Appendix 1. Carcass data were missing for two animals in replicate 1. These data were not received from Swift Canadian Limited following slaughter.

One pig in replicate one, treatment 10 died about 10 days after allotment and was replaced. The postmortem report showed that death was due to gastric ulcers leading to profuse bleeding and internal haemorrhage. A total of four pigs died in replicate 2. Three died accidentally during bleeding and the other on the 15th week of the experiment. Postmortem report showed that he suffered from torsion of the intestine, resulting in complications and death.

Blood Studies

Individual blood samples for T3 and T4 analyses were taken during the 9th and 8th week of the experiment in replicates 1 and 2 respectively by anterior vena cava puncture (Carle and Dewhirst, 1942). The samples were immediately centrifuged and about 10 ml of plasma collected for analysis. The samples were analyzed by Krahn.[1] The method of analysis is shown in Appendix 2.

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[1] P.M. Krahn, Box 87, R.R. #2, Site 9, Sherwood Park, Alberta.

TABLE 3

FORMULATION AND COMPOSITION OF EXPERIMENTAL DIETS

Diet Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ingredients (%)															
Cassava	0	20	40	0	20	40	0	20	40	0	20	40	0	20	40
Barley	80.8	57.7	34.2	73.05	46.85	20.80	59.4	28.65	0.85	76.0	48.05	32.95	64.95	39.4	14.35
Soybean Meal	13.2	17.75	22.55	8.0	11.20	14.1	-	-	-	6.0	5.25	11.0	-	-	-
Fababeans	-	-	-	12.5	16.55	21.0	32.8	44.5	54.8	11.0	21.0	12.0	27.0	34.0	40.0
Tallow	3.0	1.6	0.3	3.5	2.5	1.25	4.8	3.9	1.5	3.85	2.5	1.0	4.75	3.5	2.5
G. Limestone	1.0	0.95	0.85	0.95	0.9	0.85	1.0	0.85	0.85	1.0	0.95	0.9	1.0	0.85	0.85
Dicalcium Phosphate	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.05	0.95	1.1	1.0	1.0
Iodized Salt	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Vit Premix[1]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
T-M. Premix[1]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
L-lysine Premix										0.1	0.1	0.1	0.1	0.1	0.1
Methionine										0.05	0.1	0.1	0.1	0.15	0.20
Calculated Composition															
Crude Protein %	16.0	15.9	15.9	16.1	16.0	15.9	15.9	15.9	15.9	14.9	14.5	13.5	15.0	14.4	13.6
Lysine %	0.8	0.84	0.89	0.81	0.84	0.88	0.79	0.83	0.86	0.82	0.83	0.81	0.83	0.83	0.81
Methionine %	0.49	0.49	0.49	0.45	0.43	0.41	0.38	0.33	0.29	0.46	0.46	0.46	0.47	0.47	0.47
Ca %	0.71	0.71	0.72	0.70	0.70	0.70	0.72	0.72	0.71	0.72	0.73	0.70	0.74	0.68	0.70
Phos %	0.59	0.57	0.55	0.58	0.55	0.53	0.58	0.57	0.52	0.57	0.55	0.50	0.59	0.54	0.5
Calc. DE (Kcal/kg)	3261	3259	3263	3259	3266	3262	3265	3259	3190	3263	3259	3257	3270	3260	3259
Proximate Analysis															
Crude Prot. %	16.2	15.5	16.0	16.1	16.3	15.9	16.3	15.7	16.2	14.6	14.5	13.4	15.3	15.4	13.9
DE Kcals/kg	3274	3194	3278	3254	3102	3197	3240	3206	3016	3231	3183	3249	3157	3165	3191

[1] Supplied the following per kg of diet 4400 I.U. vitamin A; 665.5 I.U. vitamin D2; 11 i.u. vitamin E; 66 mg vitamin B12; 11.1 mg Riboflavin; 22.2 mg Calcium pantothenate; 50 mg Niacin; 55.7 mg Choline chloride; 1.65 Folic acid; It also provided Cobalt 2.8 ppm; copper 24.5 ppm; iron 294.1 ppm; Manganese 76.2 ppm, Zinc 88.5 ppm; and Iodine 1.5 ppm. In addition, it provided 110 mg oxytetracycline per kg of diet.

TABLE 4

DIETARY TREATMENTS AND ALLOTMENT OF PIGS

Periods	Starter-Grower				Finisher	
Treatment	Source of Suppl. Protein	Level of Cassava	Calculated Protein	TRT	Protein Source	Calculated Protein
1	Soybean Meal (SBM)	0	16	1	SBM	16
2	SBM	20	16			
3	SBM	40	16			
4	SBM-fababeans (FB)	0	16	4	SBM-FB	16
5	SBM-FB	20	16			
6	SBM-FB	40	16			
7	FB	0	16	7	FB	16
8	FB	20	16			
9	FB	40	16			
10	SBM-FB+amino acids(a.a.)	0	15 +a.a.	10	SBM-FB+a.a.	15 +a.a.
11	SBM-FB +a.a.	20	15 +a.a.			
12	SBM-FB +a.a.	40	14 +a.a.			
13	FB +a.a.	0	15 +a.a.	13	FB +a.a.	15 +a.a.
14	FB +a.a.	20	14 +a.a.			
15	FB +a.a.	40	14 +a.a.			

Metabolism Trials

During the 6th to 8th and 5th to 7th week of the experiment, energy and nitrogen digestibility and retention studies were carried out in replicates 1 and 2 respectively. Thirty pigs (15 barrows, 15 gilts) were used in each replicate in groups of ten each week. Selection and allotment of the pigs was such that the average weights were similar. The heavier pigs in each replicate were used in the first week of the digestibility trial and lighter pigs in subsequent trials.

Pigs were fed their respective diets during the adjustment and collection period at a level of 80-90% of the average daily feed consumed prior to the commencement of the trial. They were fed three times daily. Unconsumed feed during the period was collected, dried at 60°C in a forced air oven[2] for 3 days, weighed and deducted from the feed given.

Total fecal and urinary collections were made for three days after an initial 3 days acclimitization period as described by Castell and Bowland (1968). Representative samples of the feces were oven[3] dried at 60°C for 72 hours, weighed and ground in a Christy and Norris 8 inch laboratory mill.[4] Representative samples of the urine were freeze-dried[5] (38°C shelf temperature for 48 hours) before gross

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[2] Style 31, Dispatch Oven Co., Minneapolis, Minn., U.S.A.
[3] Style 31, Dispatch Oven Co., Minneapolis, Minn., U.S.A.
[4] Christy and Norris Ltd., Chelmsford, England.
[5] Repp Sublimator, Model SRC-42, Division of Virtis Co. Inc., Gardiner, New York, 12525, U.S.A.

energy of feces and urine were determined in a Parr Oxygen Bomb Calorimeter.[6] The energy content of individual diets was also determined with the same instrument. Kjeldahl crude protein (N x 6.25) determinations of the diet, the dried feces, aliquots of the urine and the dry matter analysis of the feed were as described in A.O.A.C. (1965). A commercial "kel-pak"[7] was used as a catalyst in the Kjeldahl analyses, the ammonia was collected in 4% boric acid and titrated with standard H_2SO_4. Metabolizable energy (ME) and nitrogen retention (NR) data by total collection method were not included in Table 11 because there were no comparable results by the HCl-digestion method.

Digestibility of the diets was also determined by 4N-HCl indicator method (McCarthy et al., 1974). The insoluble ash obtained after boiling in 4N-HCl for 30 min was used as an indicator to calculate the digestibility coefficient in a way similar to the chromic oxide method. The percent digestibility was calculated as outlined by Maynard and Loosli (1969).

$$\% \text{ Digestibility} = 100 - \left(100 \times \frac{\% \text{ Indicator in Feed}}{\% \text{ Indicator in Feces}} \times \frac{\% \text{ Nutrient in Feces}}{\% \text{ Nutrient in Feed}}\right)$$

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[6] Parr Instrument Co., Moline, Illinois, U.S.A. Temperature changes recorded by a Brown Electric Recorder manufactured by Minneapolis-Honeywell Regulator Co., Phil., Pennsylvania.
[7] Matheson Scientific, East Rutherford, New Jersey. It supplied a mixed catalyst containing HgO, k SO and CuSO .

METHODS OF STATISTICAL ANALYSIS

Analyses of variance were computed to determine if significant differences existed between the dietary combinations. The sources of variation and traits considered are presented in Table 5. Diets were considered as fixed sources of variation. The multiple comparison of means were made at the 5% ($P<0.05$) level of probability using Duncan's Multiple Range test (Steel and Torrie, 1960).

The following symbols were used to denote tests of significance.

SYMBOLS	MEANING
*	The means compared are significantly different at $P<0.05$
**	The means compared are significantly different at $P<0.01$
***	The means compared are significantly different at $P<0.001$
a, b, c, d, e	Means of the same series (column or row) bearing the same letter or no letter are not significantly different at $P<0.05$

TABLE 5

SOURCES OF VARIATION AND NUMBER OF TRAITS STUDIED

PHASE	TRAIT	DIET	SEX	REPLICATION
Starting Phase	Growth and feed consumption: 9 wk. initial wts. Average daily feed Average daily gain Kg feed/kg gain	15	2	2
	Metabolism studies: Energy and nitrogen digestibility by HCl-digestion and total collection	15	2	2
	Blood studies: T3 and T4 levels	15	2	2
Finishing Phase	Growth and feed consumption: 9 wk-market wt Average daily feed Average daily gain Kg feed/kg gain	5	2	2
	Carcass analysis: Days to market Market weight (kg) Carcass weight (kg) Dressing (%) Total backfat (cm) Length of side (km) Lean in ham face (%) Ham wt/carcass wt (%) Loin area (sq cm) Lean area ham/ham wt. sq cm/kg	5	2	2

Standard errors of means[8] are also indicated. Digestibility studies were computed considering diets as a source of variation.

In the case of treatment 3, replicate 1 where one pig died during the starting phase, data of the surviving pigs were used. Means were used to estimate missing data in replicate 2 (finishing phase). Data for feed consumption were calculated on the basis of pig-days and average daily gains were based on total gains per pig divided by the pig-days. EFC were based on the total feed intake per pen, per phase.

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[8] Standard Error of the Means $= \sqrt{\frac{\text{Error mean square}}{\text{Number of observations}}}$

RESULTS AND DISCUSSION

The results of this trial are discussed under the following headings:

A. Growth performance during starting and finishing phases
   (a) Average daily feed intake
   (b) Average daily gain
   (c) Feed conversion efficiencies

B. Digestibility of the diets
   (a) DE
   (b) DN

C. Thyroid status (starting phase only)
   T3 and T4 levels

D. Carcass characteristics

A. Growth Performance--Starting Phase

There was no significant difference in initial weights of pigs between treatments and between replicates. The performance of the pigs fed the various diets during the starting phase is shown in Table 6.

(a) Average Daily Feed Intake (ADFI)

Feed consumption data were collected on pen basis but ADF was determined on the basis of pig-days to enable comparison to be made between diets. There was no significant difference ($P<0.05$) in ADFI between diets 1, 2, 3, 4, 5, 6, 10, 11, 12, 13 and 14. Pigs fed diets 7, 8, 9 were similar and statistically ($P<0.05$) lower in ADFI than those listed above, while those fed diet 15 were

TABLE 6

PERFORMANCE OF PIGS DURING STARTER PHASE

DIET	SOURCE OF PROTEIN	LEVEL OF CASSAVA	Avg daily gain KG	Avg daily feed KG	E.F.C.[1] KG FEED/ KG GAIN
1	SBM	0	0.34abc	0.97ab	2.92c
2	SBM	20	0.39a	1.06a	2.71c
3	SBM	40	0.35abc	0.91abc	2.82c
4	SBM - FB	0	0.34abc	1.02a	3.09c
5	SBM - FB	20	0.29abc	0.87abc	3.13c
6	SBM - FB	40	0.30abc	0.86abc	2.88c
7	FB	0	0.14ef	0.67cd	5.06ab
8	FB	20	0.12ef	0.68cd	6.09a
9	FB	40	0.09f	0.52d	6.36a
10	SBM-FB+a.a.	0	0.38a	1.02a	2.72c
11	SBM-FB+a.a.	20	0.32abc	0.95ab	3.00c
12	SBM-FB+a.a.	40	0.36ab	0.96ab	2.76c
13	FB + a.a.	0	0.24cd	0.81abc	3.53c
14	FB + a.a.	20	0.27bcd	0.87abc	3.19c
15	FB + a.a.	40	0.19de	0.73bcd	3.89bc
Replicates					
1			0.29	0.90	3.52
2			0.26	0.82	3.70
Grand Mean			0.27	0.86	3.61
S.E. of Mean			0.032	0.082	0.47

1 EFC = efficiency of feed conversion

intermediate in ADFI. Addition of lysine + methionine resulted in a non-significant trend toward increased ADFI in diets 10, 11, 12, 13, 14 and 15 over 4, 5, 6, 7, 8, 9. The inclusion of cassava at up to 40% did not significantly decrease ADFI within each dietary group, but pigs fed 40% cassava ate about 13% less feed than those on no cassava diets. The reduced feed intake was most pronounced on the 100% FB diets. The poor palatability of FB combined with cassava at such high levels could have contributed to this reduced feed consumption.

(b) Average Daily Gain (ADG)

The results for ADG followed a similar trend to average daily FI. The best ADG were obtained on diets 2, 10, 12 and 4. There was no significant difference ($P<0.05$) between diets 1, 2, 3, 4, 5, 6, 10, 11 and 12. Diets 7, 8, 9 produced the poorest gains and were significantly different ($P<0.05$) from all other diets. The ADG on diets 13, 14 and 15 were intermediate between those of diets 1, 2, 3, 4, 5, 6, 10, 11, 12 and diets 7, 8, 9. The addition of lysine + methionine to diets 4, 5, and 6 (10, 11, 12) did not significantly improve ADG.

Aherne (1974) indicated that there is generally no significant improvement from methionine supplementation of FB-based diets. Stothers (1974) got conflicting results. He observed that methionine supplementation improved FI and ADG but impaired EFC. Davidson (1973) observed improved egg production when he supplemented FB laying diets (15% level) with methionine.

The inclusion of cassava at up to 40% level had no adverse effect on ADG with any of the diets. This result agrees with that of Aumaitre (1969) that cassava can be included in starter rations at up to 40% level without adverse effects. However, Aumaitre indicated that this was true only when there is a proper balance of amino acids in the diet. In the current study, amino acid balance of the diet did not significantly alter the response to inclusion of cassava in the diet.

There was a significant sex effect on weight gain during the starter phase. Barrows gained faster than gilts in all treatments. This finding agrees with those of Bowland (1974) and Bowland et al. (1975).

(c) Feed Conversion

There was no significant difference in EFC between treatments 1, 2, 3, 4, 5, 6 and 10, 11, 12, 13, 14. Diets 7, 8, and 9 were significantly different ($P<0.05$) from the other diets.

The parameters measured above suggest that FB can be included in pig starter rations at up to 21% of the diet but should not be fed as a sole protein source. Cassava can be included in pig starter rations at up to 40% of the diet without any adverse effects.

Growth Performance--Effect of level of Cassava on Performance of Pigs

Table 7 show the effect of 0, 20 and 40% cassava in the diet on the performance of pigs during the starting phase.

TABLE 7

EFFECT OF LEVEL OF CASSAVA ON PERFORMANCE OF PIGS DURING STARTER PHASE

Level of Cassava	ADF (kg)	ADG (kg)	EFC (kgfeed/ kg gain)
0	0.88	0.27	3.60
20	0.84	0.25	3.85
40	0.77	0.24	3.97
S.E. of mean	0.026	0.01	0.15

The results indicate that there were no significant differences in ADF, ADG, and EFC with up to 40% cassava in the diet. There was, however, a trend towards reduction in ADF, ADG, and EFC with increase in the level of cassava. This could be due to the dustiness of the diet with increased level of cassava and resultant low ADF.

The effect of the previous inclusion of cassava in starter diets on the performance of pigs during the finishing phase is shown in Table 10. There was again no significant difference in ADF, ADG, and EFC between the different levels of casava inclusion.

The results indicate that up to 40% cassava can be included in pig starter rations without any adverse effect on their performance or the subsequent performance of the pigs later on in life.

Growth Performance--Finishing Phase (ADG, ADF and EFC)

The performance data during the finishing period of this trial is presented in Table 8. Because pigs on treatment 7 and 13 grew more slowly during the starter phase, they needed more total pig-days to reach market weight. These treatments were therefore significantly different ($P<0.01$) from treatments 1, 4 and 10 for total gain during the finishing phase and for ADG. Pigs on treatment 7 and 13 appear to have made adequate daily gains in spite of the poor performance during the starter phase. Pigs on treatments 1, 4 and 10 made ADG above average expectation (A.R.C., 1967; N.R.C., 1973). These results tend

TABLE 8

PERFORMANCE OF PIGS DURING FINISHING PHASE

	DIETS						Replicate		
PROTEIN SOURCE	1 SBM	4 SBM-FB	7 FB	10 SBM-FB +a.a.	13 FB+ a.a.	S.E. OF MEAN	1	2	S.E. OF MEAN
Initial Weight (kg)	30.1	25.5	13.2	28.3	20.7	0.65			
Final Weight (kg)	85.6a	84.1a	79.0b	86.2a	86.7a	0.97			
Total Gain (kg)	55.5b	58.6b	65.8a	57.9b	66.0a	1.75	60.0	61.7	1.56
ADG (kg)	0.85a	0.82a	0.58c	0.83a	0.79b	0.007	0.77	0.78	0.006
ADF (kg)	2.72a	2.67a	1.97c	2.71a	2.55b	0.024	2.51	2.53	0.02
EFC (kg feed/ kg gain)	3.22	3.24	3.37	3.28	3.25	0.030	3.29	3.26	0.03

TABLE 9

EFFECT OF STARTER DIETS ON PERFORMANCE
DURING FINISHING PHASE

STARTER DIETS	FINISHING PHASE					
	INITIAL WT (KG)	FINAL WT (KG)	TOTAL GAIN (KG)	ADG (KG)	ADF (KG)	KG FEED/ KG GAIN
1	33.2	85.9	58.7	0.88	2.68	3.04e
2	30.5	87.1	56.6	0.83	2.65	3.20def
3	32.2	84.0	51.8	0.83	2.84	3.43ab
4	27.1	84.6	57.5	0.86	2.76	3.22cde
5	24.4	83.6	59.2	0.79	2.73	3.45 ab
6	24.9	84.0	59.1	0.82	2.53	3.07ef
7	14.7	79.3	64.6	0.57	2.02	3.56a
8	13.4	80.6	67.2	0.59	1.97	3.36bcd
9	11.4	77.0	65.6	0.60	1.92	3.21def
10	30.0	86.3	56.3	0.83	2.79	3.37bcd
11	25.9	86.3	60.4	0.84	2.60	3.11ef
12	28.8	85.9	57.1	0.81	2.73	3.38bc
13	21.1	86.7	65.6	0.77	2.57	3.37bcd
14	23.2	87.2	64.0	0.80	2.46	3.08ef
15	17.8	86.1	68.3	0.79	2.60	3.29bcd
S.E. of Mean	1.46	1.94	3.02	0.012	0.042	0.052

TABLE 10

EFFECT OF LEVEL OF CASSAVA IN STARTER DIETS ON PERFORMANCE OF PIGS DURING FINISHING PHASE

	FINISHING PHASE				
Level of Cassava	Initial Weight (kg)	Final Weight (kg)	ADF (kg)	ADG (kg)	EFC kgfeed/ kg gain
0	23.2	84.6	2.56	0.78	3.31
20	21.1	84.9	2.48	0.77	3.24
40	20.7	83.4	2.52	0.77	3.27
S.E. of Mean	0.65	8.67	0.0019	0.005	0.0023

to support the concept of compensatory growth responses following a period of restricted nutrition (Zimmerman and Khajarern, 1973; Wyllie et al., 1969). There were no significant sex or replicate effects. The results for ADF followed the same trend as for ADG. Pigs on treatments 7 and 13 consumed significantly less feed per day ($P<0.001$) than pigs on treatments 1, 4 and 10. There was no significant difference between treatments for EFC.

Effect of Starter Diets on Performance During the Finishing Phase

The 24 pigs on each finishing diet for both replicates was made up of 8 pigs from each of the starter diets. Table 9 shows the effect of the starter diets on performance during the finishing phase.

Although pigs formerly on treatments 7, 8 and 9 consumed less daily feed during the finishing phase than pigs on the other treatments, there was no significant difference between treatments for this parameter. The previous inclusion of cassava did not reduce feed intake in any of the dietary groups except in treatments 7, 8 and 9 where the level of FI decreased with increase in the level of cassava.

There was no significant difference between treatments for ADG, although relatively low ADG were made on treatments 7, 8 and 9 where pigs were fed FB. The supplementation of diets 13, 14 and 15 with lysine improved ADG over 7, 8 and 9 although this improvement was not significant. The previous inclusion of cassava in diets 7, 8, 9 and 13, 14, 15 tended

to increase daily gains but the increase was not significant.

There were significant differences ($P<0.05$) between treatments for EFC. The best EFC were obtained on diets 1, 6, 11 and 14. The starter diets did not have any significant effect on performance during the finishing phase. Diets 2 and 10 which were the best treatments during the starter phase did not produce best performance during the finishing phase.

In summary, this study indicates that ground unprocessed fababeans at levels up to 30% of the diet supplemented with adequate lysine and methionine can be fed to finishing pigs to produce results comparable to that obtained on a SBM-based diet. Castaing and Lewittel (1974) progressively substituted FB for SBM at levels of 0 - 36% of the diet for growing - finishing pigs. They noted no significant differences between diets for feed intake, ADG and EFC. They concluded that FB can be used at high levels in pig finishing diets without reducing performance. Stothers (1974) however, observed that a complete replacement of SBM by FB produced performance results slightly inferior to that of a SBM or SBM/FB rations. Bowland et al. (1975) fed FB as a sole protein supplement to finishing pigs and did not observe any significant depression in performance. The study also confirms earlier reports that a 16% protein fed throughout to growing - finishing pigs is adequate for optimum gain, feed efficiency and carcass quality (A.R.C., 1967; Kornegay et al., 1973;

McConnell et al., 1973; Pay and Davis, 1973; Davey and Frobish, 1975).

B. Digestibility Studies

Digestibility was estimated by both the 4N - HC1 digestion method (McCarthy et al., 1974) and the total collection method.

The results of the digestibility studies are shown in Table 11. Data are presented on DE coefficients, DE content of the diets, average daily DE intake; DN, DP of the diets, average daily DP intake and average daily DN intake.

The digestion coefficients for DE and DN by the total collection method were significantly higher ($P<0.001$) than those by 4N - HC1 method. Other authors generally agree with this finding. Mc Carthy et al., (1974) reported in one experiment that total collection method gave DE and DN values which were significantly higher ($P<0.01$) than those of 4N - HC1 method and in experiment 2 (without celite) obtained values that were similar. Vogtmann et al. (1975) working with broiler chickens also reported significantly higher ME - values by the total collection method as compared with the insoluble ash method. Van Keulen (unpublished data) obtained significantly higher dry matter and energy digestibility values (using sheep) by the total collection method than by the HC1 - digestion method.

There was no significant difference ($P<0.05$) for DE between dietary treatments by the total collection method. Significant differences ($P<0.01$) were however observed for

TABLE 11

ENERGY (DE) AND NITROGEN (DN) DIGESTIBILITY

Protein source	1 SBM	2 SBM	3 SBM	4 SBM-FB	5 SBM-FB	6 SBM-FB	7 FB	8 FB	9 FB	10 SBM-FB +a.a.	11 SBM-FB +a.a.	12 SBM-FB +a.a.	13 FB +a.a.	14 FB +a.a.	15 FB +a.a.	Replicates 1	2	GRAND MEAN	S.E. OF MEANS
ENERGY																			
% DE (Total collection)	80.6	78.7	82.6	79.6	78.4	80.9	82.9	80.7	77.7	79.5	80.6	83.2	78.2	78.9	81.9	79.6	81.0	80.3	1.56
% DE (Hcl-digestion)	77.9abc	76.9cd	80.8a	77.5abc	75.9bc	76.8abc	78.9d	76.4bc	78.1abc	76.1bc	77.2abc	77.9abc	74.1cd	74.6cd	79.4ab	76.6	76.6	76.6	1.30
Average % DE	79.3abc	76.8c	81.7a	78.6abc	77.1c	78.8abc	76.9c	78.5abc	77.9abc	77.8bc	78.9abc	80.6ab	76.1c	76.8c	80.7ab	78.1	78.8	78.4	1.02
DE of diet (as fed) kcal/kg	3191	3059	3260	3171	3076	3140	3095	3136	3037	3116	3141	3203	3068	3079	3214				
Average daily DE intake (kcals)	3095	3243	2967	3234	2676	2700	2074	2133	1579	3178	2984	3075	2885	2679	2386				
NITROGEN																			
% DN (Total collection)	77.0	75.0	77.8	75.3	74.7	74.5	80.5	77.2	72.7	75.9	76.1	75.3	74.3	75.4	74.8	75.0	76.5	75.7	1.95
% DN (Hcl-digestion)	76.7	70.6	75.4	73.2	71.9	69.3	66.7	72.0	73.1	71.8	71.9	69.9	69.7	70.3	71.0	71.6	71.5	71.6	1.86
Average % DN	76.9	72.6	76.6	74.3	73.3	71.9	73.6	74.6	72.9	73.9	74.0	72.6	72.0	72.9	72.7	73.3	74.0	73.7	1.36
D.P. of Diet (as fed) g/kg	124.4	113	122.2	119.8	119.2	114.0	119.6	117.8	125.0	107.7	107.4	97.1	109.8	111.8	100.8				
Average daily D.P. intake (g)	121.0	120.0	111.0	122.0	104.0	98.0	80.1	79.8	65.0	110.0	102.9	93.2	89.0	97.3	78.0				
Average daily DN intake (g)	19.3	19.2	18.0	20.0	17.0	16.0	13.0	13.0	10.4	18.0	16.3	15.0	14.2	16.0	12.0				

DE by 4N - HC1 method and consequently the mean of the two methods. The mean coefficients for DE were between 76.1 and 81.7 (mean 78.4).

The digestion coefficient for energy was significantly higher ($P<0.05$) for diet 3 than for the other diets. This improved DE was not reflected in improved performance (ADG, ADF and EFC). The NRC (1973) recommended 3500 kcal DE/kg in pig starter diets but none of the diets used in this experiment met this recommended level. Considering the GE levels of the diets which were about 4000 kcal and using the higher DE values obtained by total collection, the energy concentration of the diets might be adequate. O'Grady and Bowland (1972) suggested that the optimum level of DE for early weaned pigs fed barley-or wheat-based diets from 3 - 8 wk was 3200 - 3400 kcal/kg. The performance of the pigs on the different diets is more easily explained by the daily DE intake data. Although none of the treatments met the recommended daily intake of 4370 kcal DE (NRC, 1973), pigs fed diets 7, 8, 9, 13 and 15 were lower in daily DE intake than other diets and these pigs generally had the lowest performance.

(ii) Digestible Nitrogen

No significant differences in DN between treatments were observed in this study. There was however a significant difference in DN ($P<0.001$) between the total collection method and 4N - HC1 method. Digestibility of nitrogen or protein is usually less than digestibility of energy (Rutledge et al., 1961; Okai, 1974; McKinnon, 1974) and this

was the case in this study. The average DN was between 71.9 and 76.9 (mean 73.7). This value appears low when compared to the results of Stothers (1974) who obtained 91.1% and 95.8% for the protein digestibility of unprocessed ground FB and SBM respectively. Hebbethwaite and Davis (1971) cited Waring and Shannon (1969) as indicating that true digestibility coefficients (using colostomised laying hens) of the crude protein of spring beans was 84.0% and winter beans 81 percent. Sarwar and Bowland (1976) found the apparent protein digestibility of FB to be 82 - 83 percent. Other workers have found values that were lower or similar to those reported in this experiment (McKinnon, 1974; Aherne 1975). The digestible protein in the diet reflected the digestibility coefficients and are lower than recommended NRC values.

(c) Blood Studies

Table 12 shows the mean values of thyroxine, triiodothyronine (in ug/dl, percentage uptake and ng/dl) levels in the blood analysed. The results will be discussed for each treatment groups with increasing levels of cassava in the diets (i.e., treatments 1, 2, 3; 4, 5, 6; 7, 8, 9; 10, 11, 12; and 13, 14, 15). The effects of goitrogens on thyroid function and the importance of T3 and T4 as a measure of thyroid status had been discussed in the literature review.

(i) Thyroxine (T4)

There was no significant difference between treatment groups for this parameter except for treatment group 7, 8

and 9. For diets 7, 8 and 9, the results show a decreased level of blood thyroxine with increase in the level of cassava. Diet 9 was significantly different ($P<0.05$) from diets 7 and 8. It is not known why these differences should occur for the FB-based diets and not for the SBM or SBM - FB diets. Possibly FB itself has a synergistic effect on this difference. Maner and Gomez (1973), suggested that cyanide is without measurable effect on goitre production or nerve degeneration in the presence of adequate methionine and iodine. If this is valid, it could therefore be suggested that methionine level in FB-based diets containing high levels of cassava was not adequate, hence the results obtained. This could also explain why there was no significant difference between treatments 13, 14 and 15.

The T4 levels obtained in this trial appear lower than those reported by Hollander and Shenkman (1972) for humans and Egbuiwe (1975) for swine who got values of 4.5 - 10.5 ug/dl. The reason for this low value is not known. The results do not however show significant subnormal levels of T4 when compared to diets without cassava.

(a) T3 - Uptake

There was no significant difference between treatments or treatment groups for this parameter. The values obtained also appear to fall within the euthyroid range of 20 - 40 per cent.

(b) T3 - RIA

'RIA' indicates that the T3 level was determined by the radio-immunoassay (RIA) method.

TABLE 12

MEAN VALUES OF THYROID STATUS (T4, T3, T3-RIA)

DIETS	Protein Source	Level of Cassava	T4 ug/dl	T3 UPTAKE %	T3-RIA ng/dl
1	SBM	0	3.5a	36.9	117a
2	SBM	20	3.0abc	37.0	87bc
3	SBM	40	2.8abc	37.2	100ab
4	SBM-FB	0	2.7abc	35.5	81bc
5	SBM-FB	20	3.2ab	38.5	79bcd
6	SBM-FB	40	2.9abcd	40.6	76bcd
7	FB	0	3.2ab	38.2	83bc
8	FB	20	2.7abcde	39.1	69cde
9	FB	40	1.8e	39.4	52de
10	SBM-FB+a.a.	0	2.5bcde	33.9	79bcd
11	SBM-FB+a.a.	20	2.4bcde	39.4	83bc
12	SBM-FB+a.a.	40	2.4bcde	37.6	88bc
13	FB+a.a	0	2.2cde	37.5	91abc
14	FB+a.a.	20	2.4bcde	36.8	74bcd
15	FB+a.a.	40	2.0de	40.3	46e
Grand Mean			2.7	37.9	80
S.E. OF MEAN			0.29	0.21	0.52

There was a significant difference ($P<0.001$) between diets in treatment groups 7, 8, 9 and 13, 14, 15. Diets 9 and 15 were significantly different from 7, 8 and 13, 14 in each group. The replicates were also significantly different ($P<0.001$). There was no significant difference between diets in the other treatment groups. The differences observed with the FB-based diets 7, 8, 9; 13, 14 and 15 might be due to methionine deficiency since both FB and cassava are low in methionine.

Hollander and Shenkman (1972) indicated that normal T3 levels in human plasma is 100 - 150 ng/100 ml. By the radioimmunoassay method, the euthyroid T3 range for rats was found to be 72 - 214 with a mean of 126 ng/100 ml. (Anonymous, Mallinckrodt laboratories). When compared with the latter, the results obtained in this trial show a enthyroid status except for diets 9 and 15. This result is not readily explained since the expected effects of the goitrogens in the cassava ingested would be an elevation and not a depression of T3 level.

The importance of these results lie in the fact that since cassava may contain goitrogenic substances (Linamarin and Lotaustralin), the ingestion of high levels of cassava might affect the ability of the thyroid gland to produce optimum levels of thyroid hormones (T4 and T3) or might induce nerve degeneration. The results obtained in this trial have not shown that the T4 level is subnormal or T3 level elevated with a level of up to 40% cassava in the diet.

(d) Slaughter Age and Carcass Analysis

The mean values for slaughter age and carcass analysis is shown in Table 13. There was no significant difference between treatments 1, 4 and 10 in the number of days to market. Treatments 7 and 13 (fed FB diets) were significantly different ($P<0.001$) from 1, 4 and 10 and took longer to get to market weight (85 kg). Except for the slow growing pigs in treatment 7, all the pigs on the other treatments were marketed at an average liveweight of 85 kg. Treatment 7 was therefore significantly different ($P<0.05$) from the other treatments. The carcass weight followed the same trend as liveweight at slaughter with treatment 7 being significantly different ($P<0.05$) from treatments 1, 4, 10 and 13.

There was no significant difference between treatments for dressing percentage. Treatment 7 contained significantly ($P<0.05$) less total back fat than the other treatments. This was probably due to the slower growth rate of pigs on this treatment. The length of side for pigs on treatment 7 was significantly ($P<0.001$) shorter than those of other treatments while those on treatments 10 and 13 were longest and similar. These treatments were statistically different ($P<0.001$) from treatments 1 and 4 for this parameter. There were no statistical differences between treatments for ham wt/carcass wt. Although there was no statistical difference between treatments for area of loin, pigs on treatments 1, 4, 10 and 13 tended to have larger loin areas than pigs on treatment 7. There was no significant difference between

TABLE 13

MEAN VALUES OF SLAUGHTER AGE AND CARCASS DATA

TRAITS	Protein Source	TREATMENTS 1 SBM	4 SBM-FB	7 FB	10 SBM-FB+a.a	13 FB+a.a	Grand Mean	S.E. of Mean
SLAUGHTER AGE (DAYS)*		157a	164.8a	214.8c	161.6a	174.6b	174.7	2.09
LIVEWEIGHT AT SLAUGHTER (kg)		85.6a	84.1a	79.0b	86.2a	86.7a	84.3	0.97
CARCASS WT (KG)		68.2a	66.4a	62.2b	68.9a	69.3a	67.1	0.80
Dressing %		79.7	79.0	78.8	80.1	80.0	79.5	0.31
TOTAL BACKFAT (CM)**		9.9a	9.9a	9.3b	10.2a	10.2a	9.9	0.13
LENGTH OF SIDE (CM)		75.9a	75.5a	73.9b	76.7c	77.2c	75.8	0.12
Ham wt/carcass wt (%)		26.1	26.2	25.6	26.1	25.7	25.9	0.30
Area of loin (cm^2)		29.3	28.8	25.2	28.8	29.0	28.2	0.77
Lean in ham face (%)		53.5	52.5	55.1	51.1	52.4	52.9	1.60
Lean area ham/ham wt sq cm/kg		16.0	15.9	17.0	15.1	16.2	16.4	0.46
Grade Index		100.4	99.8	96.6	100.8	101.3	99.7	0.98

* adjusted to 85 kg slaughter weight

** sum of three measurements (shoulder, loin and back)

treatments for lean in ham face, lean area ham/ham weight and Grade Index measurements. The overall carcass results indicate that none of the supplemental protein sources fed had any major adverse effects on carcass measurements. The fact that there were very few significant differences in the carcasses as a whole, demonstrates among other things, the remarkable recuperative capacity of pig tissues, a fact brought out by McMeekan (1940 c.).

SUMMARY

Associated with the high price of feed grains and protein supplements since 1973, and the increased use of these feedstuffs by humans, efforts have been intensified by nutritionists to find alternative energy and protein sources for livestock feeding. Studies to determine the effects of partial or total replacement of SBM by FB on the performance of starting - finishing pigs and the effects of inclusion of up to 40% cassava in pig starter diets were carried out at The University of Alberta, Edmonton Research station.

The results indicate that partial replacement of SBM by FB had no adverse effects on the performance of starter pigs. ADF, ADG and EFC of pigs receiving diets containing up to 21% FB were not significantly different from the SBM-based diets. Lysine and methionine supplementation of the diets containing FB did not significantly improve performance. When FB completely replaced SBM, ADF, ADG and EFC were significantly depressed. Lysine and methionine supplementation of these diets significantly improved performance but not up to a level equivalent to diets containing SBM or SBM-FB. The inclusion of cassava at up to 40% of the diet had no adverse effects on performance or on thyroid function as measured by the levels of T3 and T4 in the plasma.

During the finishing phase, the FB diets supplemented with lysine and methionine produced significantly lower ($P<0.05$) ADF and ADG than the SBM or SBM-FB diets. Unsupplemented FB diets were significantly inferior to the

other diets.

Pigs on the unsupplemented FB diets were lighter at slaughter and took longer to get to market weight than the other pigs. There were no significant differences between most of the carcass traits measured (Dressing %, ham weight/carcass weight %, loin area, lean in ham face, lean area ham/ham weight and Grade Index).

Digestion coefficients of DE and DN by the 4N-HC1 method were significantly lower ($P<0.01$) than by the total collection method. There were no significant differences between treatments for DE determined by the total collection method or for DN determined by either the total collection method or 4N-HC1 method.

The present study demonstrates that a 50:50 combination of SBM-FB, supplemented or unsupplemented with lysine and DL-methionine can be used in pig starter diets to produce results similar to that obtained on a SBM supplemented diet. Cassava can also be included in such diets at a level of up to 40% without a reduction in performance or measurable change in thyroid function. FB-supplemented diets with added lysine and methionine may be fed as finishing diets to produce comparable, although slightly lower performance than SBM or SBM-FB supplemented diets. The results also confirm earlier findings that diets containing 16% crude protein can be fed satisfactorily to pigs from starting to finishing.

BIBLIOGRAPHY

Agricultural Research Council, 1967. The nutrient requirements of farm livestock, No. 3. Pigs. Technical Reviews and Summaries, ARC, London.

Aherne, F.X. 1974. Fababeans as a protein supplement. Agric. Bull, Summer 1974. 53rd Annual Feeder's Day Report. Univ. of Alberta, Edmonton.

Aherne, F.X. 1975. The use of fababeans in diets for growing pigs. Univ. of Alberta 54th Feeder's Day Report, p. 3.

Aherne F.X. and McAleese D.M. 1964. Evaluation of tick beans (vicia faba.L) as a protein supplement in pig feeding. Sci. Proc. B. Royal Dublin Soc. 113-121.

Aherne, F.X., Bowland, J.P., Berg, R.T. and McQuity, J.B., 1974. Swine Production in Alberta. Dept of Animal Sci., Faculty of Agric., U of A, Bull 22, 12th ed.

Alba, M.C. 1937. A study of different varieties of cassava for hog feeding purposes. The Phil. Agric. 25: 782-798.

Anonymous, 1972. Feeding Field Beans. Feedstuffs Nov. 27, 1972.

Anonymous, 1972. RIA-MAT Circulating T3 1125 Kit for in vitro quantitative determination of serum Liothyronine(T3). Mallinc Krodt Chemical Works. St. Louis. pp 1-11.

Asico, P.M. 1941. A comparative study of gaplek meal and corn as basal feed for growing and fattening pigs. Phil. Agric. 29: 706-711.

Assis, F.T., Da Rocha, G.L., Medina, P., Guasagna, R.N., Becker, M., Pohl, R., and Kalil, E.B., 1962. Effect of giving roots and tubers as supplement in winter to lactating cows. Biol. Indust. Anim. Sao Paulo, 20: 55-61.

Association of Official Agricultural Chemists. Official Methods of Analysis (10th ed.) Washington, D.C. 1965.

Ayres J.C. 1972. Manioc: The potential exists for increased use of this tropical plant and its product. Food Techn. April, 1972.

Balu, V. and Parpia, H.A.B., 1958. Tapioca macaroni goes to the people. Food. Sci. Ext. Bull, No. 1, Div of Food Inf, and Stat., Central Food Tech. Res. Inst. Mysore, India.

Berry, T.H., Combs G.E., Wallace H.D., and Robbins, R.C.,

1966. Responses of the growing pig to alterations in the amino acid pattern of isolated soybean protein. J. Anim. Sci. 25:722.

Bissett F.H., Clapp, R.C., Coburn, R.A., Ettlinger, M.G. and Long, L., Jr. 1969. Cyanogenesis in Manioc: concerning Lotaustralin. Phytochem. 8:2235-2247.

Bolhuis, G.G. 1954. The toxicity of Cassava roots. Neth, J. Agr. Sci. 2(3):176.

Bond, D.A. and Toynbee-Clarke G., 1968. Protein content of spring and winter varieties of field beans sown and harvested on the same dates. J. Anim. Sci. Camb. 70:403-404.

Boshell, J. 1968. Ann. report (appendix) Belem Virus Lab, Belem, Brazil.

Bowland, J.P. 1970. Protein and amino acid requirements for market pigs. Univ. of Alberta Feeders day, 49th annual report P.1.

Bowland, J.P. 1974. Comparison of low glucosinolate rapeseed meal, commercial rapeseed meal and soybean meal as protein supplements for growing pigs. Can. J. Anim. Sci. 54:679-685.

Bowland, J.P. and Grimson R.E., 1969. Lysine and methionine supplementation of swine and fat diets containing up to 3% urea. Wissenschaftliche, Zeitschrift Der Universitat Bostock - 18 Jahrgang 1969. Mathematisch-Naturwissenschaftiliche Reihe, Heft 1/2 Herausgeber: Der Recktor.

Bowland, J.P., Aherne, F.X., and Egbuiwe, A.M., 1975. Fababeans and low glucosinolate rapeseed meal as supplemental protein sources for growing-finishing pigs. Univ. of Alberta 54th Annual Feeders' Day Report P. 9.

Bowland, J.P. and Orok E.J., 1973. Rapeseed meal and peanut meal as complementary protein supplements for starting growing pigs. Univ. of Alberta 52nd Ann. Feeders' Day Report P. 6.

Bragg, D.B. and Kitts, W.D., 1975. Cassava (tapoica) as an alternative energy source. Proc. of 10th Annual Pacific Conf., Portland, Oregon. pp. 57-67.

Brown, H.D., Harmon, B.G., and Jensen, A.H., 1973. Lysine requirement of the finishing pig for maximum carcass leanness. J. Anim. Sci. 37: 1159.

Brown, H.D., Harmon, B.G., and Jensen, A.H., 1973. Lysine

requirement of the finishing pig for maximum rate of gain and efficiency. J. Anim. Sci. 37:708.

Canada Grain Council 1972. Use of fababeans in swine feeding. "In European experience with the small fababean (Horse bean)" Winnipeg Canada.

Carle B.N. and Dewhirst W.M.H. Jr. 1942. A method for bleeding swine. J. Amer, Vet. Med. Assoc., 101:495-496.

Carpenter K.J. and Johnson, C.L. 1968. The matabolisable energy of field beans for poultry. J. Agric. Sci. 70:391-392.

Castaing J. and Lewittel M. 1974. Progressive substitution of soybean oil meal by shelled horse bean in growing-finishing pig diets. Journes de la Recheche Porcine en France 1974.

Castell, A.G. and Bowland J.P. 1968. Supplemental copper for swine: growth digestibility and carcass measurements. Can. J. Anim. Sci. 48:403-413.

Chamberlain, A.G., 1971. Protein requirement of the growing pig: In Pig Production - proceedings of the 18th Easter School in Agric. Sci. Ed. A.J.A. Cole. Univ. of Nottingham, Butterworths, London.

Clandinin, D.R., 1949. The effects of methods of processing on the nutritive value of herring meals. Poult. Sci. 28:128.

Clandinin, D.R., and Robblee, A.R., 1952. The effect of processing on the enzymatic liberation of Lysine and arginine from soybean oil meal. J. Nutr. 46:525-530.

Clapp, R.C., Bissett, F.H., Coburn, R.A., and Long, L., Jr. 1966. Cyanogenesis in Manioc: Linamarin and isolinamarin. Phytochem. 5:1323-1326.

Clarke, H.E. 1970. The evaluation of the field bean (vicia fab.L) in animal nutrition. Proceedings of the Nutr. Soc. 29: (1) 64-73.

Clausen, H.J. 1965. The protein requirements of growing meat type pigs. World Rev. Anim. Prod. 1 (1) 28-42.

Close, J., Adriaens, E.L., Moore, J., and Bigwood, E.J., 1953. Composition en acides amines d'hydrolysates de farine de manioc roui, variete Amere. Bull. Soc. Chem. Biol. Brussels 35:985.

Couch, J.F. 1932. U. S. Department of Agr. leaflet 88.

Coursey, D.G. 1973. Cassava as food. Toxicity and

technology. In chronic cassava toxicity ed. Barry Nestel and Reginald MacIntyre. Int. Dev. Res. Centre 010e Ottawa.

Coursey, D.G. and Haynes, P.H. 1970. Rootcrops and their potential as food in the tropics. World Crops July/Aug: 261-265.

Cromwell, G.L., Pickett, R.A. and Beeson, W.M. 1967. Nutritional value of Opaque-2 corn for swine. J. Anim. Sci. 26:1325.

Culwick, G.M. 1950. A dietary survey among the Zande of the Southern Sudan. In Hendershott: A literature review and research recommendations on Cassava. P. 7.

Davey, R.J. and Frobish, L.T., 1975. Diet protein sequence and added lysine for growing-finishing swine. Amer. Soc. Anim. Sci. (Abstracts). 67th Annual Meeting July 26-July 30, 1975. Colorado State Univ. Fort Collins, U.S.A.

Davidson, J. 1973. The nutritive value of field beans for laying hens. Br. Poult. Sci. 14:557-567.

De Bruijn, G.H. 1973. The cyanogenic character of cassava (Manihot esculenta). In chronic cassava Toxicity: Proceedings of interdisciplinary workshop, London, England. Int. Dev. Res. Centre. Monogr. IDRC OIO - 43:48, Ottawa.

Eden, A. 1968. A survey of the analytical composition of field beans. J. Agric. Sci. Camb. 70:299-301.

Ekpechi O.L., Dimitriadou, A., and Fraser, R., 1967. Goitrogenic activity of cassava (a staple Nigeria food). Nature (London) 210:1137-1138.

Ekpechi, O.L. 1973. Endemic goitre and high cassava diets in Eastern Nigeria. In Chronic Cassava Toxicity: 139-146. Proceedings of Interdisciplinary workshop London, England. Ed. Barry Nestel and Reginald MacIntyre. Inter. Deve. Res. Centre Monogr. IDRC OIOe, Ottawa.

Elman, R. 1939. Time factor in retention of nitrogen after intravenous injection of mixture of amino acids. Proc. Soc. Expt. Bio. Med. 40:484.

Evans, L.E., 1974. Fababean varieties: present and future: in First National Fababean Conference, Marlborough Hotel, Winnipeg, Manitoba, Feb. 21, 22.

Ferree, C.J., 1929. The soybean and the new soya. (Revised and Translated by C.J. Ferree and T.J. Tussaud). William Heinemann (Medical Books) Ltd., London.

Food and Agriculture Organisation of the United Nations, 1970. Production Yearbook Vol. 24, Rome.

Food and Agriculture Organisation of the United Nations, 1972. Production Yearbook, Vol 25:116-120, Rome.

Food and Agriculture Organisation of the United Nations, 1974. Production Yearbook, Rome.

Promagest C., and Royes, A., 1945. Sur les groupements actifs de la cysteinose of B. subtilis. Enzymologia 11:361-367.

Gallo, J.T. and Pond W.G., 1968. Amino Acid supplementation of all-corn diets for pigs. J. Anim. Sci. 27:73-78.

Godoy, J.M., 1940. Fecularia e Amidonaria. 2nd Ed. Sao Paulo, Brazil.

Greer, M.A., Grimm Y. and Stiader, H. 1968. Quantitative changes in the secretion of thyroid hormones induced by iodine deficiency. Endocr. 83:1193-1198.

Gross, J., and Pitt-Rivers, R., 1952. The identification of 3:5:3-L-triiodothyronine in human plasma. Lancet 1:439.

Gross J. and Pitt-Rivers, R., 1952. Physiological activity of 3:5:3-L-triodothyronine. Lancet 1:593-594.

Hare, J.H. and Sabeh, H.J., 1974. Tapioca in livestock feeds. Prepared for: Mitsui and Co (Canada) Ltd. 505 Burrard Street, Vancouver, B.C.

Hare, J.H. and Associates Ltd. Tapioca in livestock feeds. 986 Grain Exchange Building, 167 Lombard Avenue, Winnipeg, Manitoba, Canada.

Harper, A.E., Benevenga, N.J. and Wohlhuetes, R.M. 1970. Effects of ingestion of disproportionate amounts of amino acids. Physiol. Review: 50:428-531.

Hays, V.A., Speer, V.C., Hartman, P.A. and Castron, D.V., 1959. The effects of age and supplemental amino acid on the utilisation of milk and soya protein by the young pig. J. Nutr. 69:179.

Hebblethwaite, P.D., and Davis, G.M. 1971. Nutritive value and utilisation of field beans (vicia faba. L) for livestock feed. Agricultural Progess Vol XLVI (46): 26-31.

Hendershott, C.H., Ayres, J.C., Brannen, S.B., Dempsey, A.H., Lehman, P.S., Obioha, F.H., Rogers, D.G., Seerley, R.W. and Tan, K.H., 1972. A literature review and research recommendations on cassava (Manihot

esculenta, Crantz). Univ. of Georgia, Athen, Georgia.

Hill, D.C. 1973. Chronic cyanide toxicity in domestic animals. In Chronic Cassava Toxicity: 105-111. Proceedings of Interdisciplinary Workshop London, England. Ed. Barry Nestel and Reginald MacIntyre. Int. Dev. Res. Centre Monogr. IDRC-OIOe, Ottawa.

Himwich, N.H. and Saunders, J.P., 1948. Enzymatic conversion of cyanide to thiocyanate. Amer. J. Physiol. 153:348-354.

Hollander, C.S. and Shenkman, L., 1972. The physiological role of triiodothyronine. Amer. J. Med. Sci. 264:4-7.

Hollander, C.S., Mitsuma T and Shenkman, L. 1971. Hypertriiodothyronineaemia as a premonitory manifestation of thyrotoxicosis. Lancet II:731-733.

Howorth, P.J. and Maclagan, N.F. 1969. Clinical application of serum total thyroxine estimation, resin uptake and free-thyroxine index. Lancet I: 224-228.

Jadot, J. and Maghium-Rogistes, G., 1968. A new dissacharide extracted from manioc flour. I. Establishment of the structural formula. Bull. Soc. Chim. Belg, 77:569-574.

Johnson, R.M., and Raymond, W.D. 1965. The chemical composition of some tropical food plants. 4. Manioc. Trop. Sci. 7(3) 109-115.

Jones, W.O., 1959. Manioc in Africa. Stanford Univ. Press, Stanford California, U.S.A.

Jones, J.D. 1964. Lysine - arginine antagonism in the chick J. Nutr. 84:313.

Jones, J.D., Peterburg, S.J., and Burnett P.C., 1967. The mechanism of the lysine-arginine antagonism in the chick: Effect of lysine on digestion, kidney arginase and liver transfer amidinase. J. Nutr. 93:103-116.

Keele, C.A. and Neil, E. 1966. "Samson Wright's applied physiology" 11th ed. Revised by C.A. Keele and Eric Neil London, Oxford Univ. Press, N.Y., Toronto.

Ketiku, A.O. and Oyenuga, V.A., 1972. Changes in carbohydrate constituents of cassava root-tuber (Manihot Utilissima Pohl) during growth. J. Sci. Fd. Agric. 23:1451-1456.

Khayambashi, H. and Lyman, R.L., 1969. Secretion of rat plasma perfused with plasma from rats fed soybean trypsin inhibitor. Amer. J. Physiol. 217:646-651.

Kornegay, E.T., Thomas, H.R. and Carter, J.H., 1973. Evaluation of dietary protein levels for well muscled hogs. J. Amin. Sci. 36:79.

Kwong, E., and Barnes, R.H., 1963. Effect of soybean trypsin inhibitor on methionine and cystine utilisation. J. Nutr. 81:392.

Lang, S., 1933 a, b. Die Rhodanbilduny in Tierkosper. Biochem 2, 259: 243-247. 1933 b. Die Rhodanbilduny in Tierkosper, Biochem. 259: 262-266.

Liener, I.E., 1958. In processed plant protein foodstuffs. A.M. Altschul, ed., chap 5. Academic Press, New York.

Lyman, R.L. and Lepkovsky, K., 1957. The effect of raw soybean mean and trypsin inhibitor diets on pancreatic enzyme secretion in the rat. J. Nutr. 62:269-284.

Maghuin-Rogister, G., 1968. A new disaccharide extracted from manioc flour II. Synthesis of glucophyanosyl d-glucofuranose. Bull. Soc. Chim. Belg. 77:575-578.

Mahan, D.C., Swinger, L.A., Cline, J.H. and Parrett, N.A., 1973. Effect of varying protein levels for growing swine with a constant level for finishing. J. Anim. Sci. 37:285.

Makene, W.J. and Wilson J., 1972. Biochemical studies in Tanzanian patients with tropical ataxic neuropathy. J. Neurol. Neurosurg. Phychiat. 35:31-33.

Maner, J.H., 1973. "Cassava in Swine feeding" Centro International de agricultura Tropical. Bull. RB-1. May, 1973.

Maner, J.H. and Daniels, A.L., 1970 and 1971. In cassava for swine feeding. CIAT Bull. RB-1. 1973.

Maner, J.H. and Gomez, G., 1973. Implications of cyanide toxicity in animal feeding studies using high cassava rations. In Chronic Cassava Toxicity:113-123. Proceedings of Interdisciplinary Workshop, London, England. Int. Dev. Res. Centre Monogr, IDRC-OIOe. Ottawa.

Martino, G., 1935. On the nutritive value of cassava. Bull. Inst. Fisiol. Asuncion (Paraguay), No. 15.

Mathur, M.L., Sampath, J.R. and Gosh, S.N., 1969. Studies on cassava: effect of 50% and 100% replacement of oats by tapioca in the concentrate mixture of dairy cows. J. Dairy Sci. 22:193-199.

Maynard, L.A., and Loosli, B.K., 1969. In "Animal Nutrition"

6th ed. McGraw-Hill Book Co. New York, St. Louis, San Francisco, London, Sydney, Toronto, Mexico, Panama. P. 352.

McCarthy, J.F., Aherne F.X. and Okai, D.B., 1974. Use of insoluble ash as an index material for determining apparent digestibility with pigs. Can. J. Anim. Sci. 54:107-109.

McConnell, J.C., Banks, C.M., Handlin, D.L. and Skelley, G.C., 1973. Protein level and sequences for barrows and gilts. J. Anim. Sci. 37:203 (abstr).

McKinnon, P.J., 1974. Comparison of broken rice or corn as dietary ingredients for starting pigs and weanling rats. Master's Thesis, Dept. of Anim. Sci., Univ. of Alberta, Edmonton.

McMeekan C.P. 1940c. Growth and development of the pig with special reference to carcass quality characteristics. III Effects of plane of nutrition on the form & comp. of the bacon pig. J. Agric. Sci. 30(4): 511-569.

Meister, F.C., and Fries, E.E., 1953. The metabolism of thiocyanate after prolonged administration in man. Ann. Biochem. Exp. Med. 23(3): 549-553.

Melmed, R.N. and Bouchier, I.A.D., 1969. A further physiological role for naturally occuring trypsin inhibitors: the evidence for trophic stimulant of the pancreatic acinar cell. Gut 10:973-979.

Melnick, G.B., Oser, R. and Weiss, S., 1946. Rate of enzymatic digestion as a factor in nutrition. Science 103:326.

Mondonedo, M. and Alonte, F., 1931. A comparative study of corn, cassava, sweet potatoes, and pong-apong as feed for swine. Phillipine Agric. 20:113-119.

Mondonedo, M., 1928. A comparative study of corn and cassava as feeds for hogs. II Ground corn vs. raw chopped cassava. Phillipine Agri. 17(2) 105-107.

Morgan, J.H., 1970. A review of field bean in human diets. R. H. M. Agric. Res. and Advisory Serv. Rep.

Morris, J.R. and Luckham, D.G., 1975. Supplemental amino acids in swine rations. Agr. Inst. Canada Conf. (Abstract) Manitoba, Winnipeg.

Muelenaere, J.H.J. de., 1964. Studies on digestion of soybeans. J. Nutr. 82:197.

Mukerji, M. and Smith., R.G., 1943. The chemistry and

pharmacy of vitamin b in experimental cyanide posioning. Ann. Biochem. Exp. Med. 3: 23-41.

Nartey, F., 1968. Studies on cassava (Manihot utilissima, Pohl.) 1. Cyanogenesis: The biosynthesis of Linamarin and Lotaustralin in etiolated seedlings. Phytochem. 7:1307-1312.

Nartey, F. 1973. Biosynthesis of Cyanogenic glucoside in cassava (Manihot spp.) PP 73-87. In chronic cassava toxicity: Int. Develop. Res. centre Monogr. IDRC-010e.

National Research Council - National Academy of Sciences. Nutrient requirements of swine #2. 7th revised ed. Washington D.C. 1973.

Nestel, B., 1974. Current trends in Cassava Research. Int. Dev. Res. Centre Monogr. IDRC-036e, Ottawa.

Nicol. B.M., 1952. The nutrition of Nigerian peasants with special reference to the effects of deficiencies of the vitamin B complex, vitamin A and Animal protein. Brit. J. Nutr. (Camb.) 6:1.

Nicholls, L., 1957. Tropical Nutrition and dietetics. London.

Newman, C.W., and Elliot, D.O., 1975. L-lysine and DL-methionine supplements in barley-soy pig diets. Proc. Western Sec. Amer. Soc. Anim. Sci., 26:105-107.

O'Grady, J.F. and Bowland, J.P., 1972. Response of early weaned pigs to diets of different digestible energy concentrations and the effects of cereal source and added molasses on performance. Can. J. Anim. Sci. 52:87-96.

Okai, D.B., 1974. Effects of diet complexity on feed intake and performance of piglets and effects of creep intake and composition on starter intake and baby pig performance. Master's Thesis, Dept. of Anim. Sci. Univ. of Alberta., Edmonton.

Oke, O.L., 1969. The role of HCN in nutrition. World Rev. Nutr. and Diet. 11:170.

Oke, O.L., 1978. The mode of cyanide detoxication. In chronic cassava toxicity: 97-104. Proceedings of Interdisciplinary Workshop, London, England. Int. Dev. Res. Centre. Monogr. IDRC 010e, Ottawa.

Oluwasanmi, J.O., and Alli, F.O., 1968. Goitres in Western Nigeria. Trop. Geogr. Med. 20:357-366.

Oppenheimer, J.H., 1968. Role of plasma proteins in the

binding, distribution and metabolism of thyroid hormones. N. Engl. J. Med. 178: 1153-1172.

Orok, E.J. and Bowland, J.P., 1974. Nigerian cocao husks and cassava meal as sources of energy for rats fed soybean meal or peanut meal supplemented diets. Can. J. Anim. Sci. 54:229-238.

Orr, D.E., 1973. Lysine and methionine supplementation in swine rations. Mich. Agri. Expt. Stat. Rep. 232. Att-Sw-7315.

Osborne, T.B., and Mendel, L.B., 1917. The use of soybeans as food. J. Biol. Chem. 52:369.

Osborne, T.J. and Mendel, L.B., 1914. Amino acids in nutrition and growth. J. Biol. Chem. 17:325-349.

Oshuntokun, B.O., 1971. The epidemiology of tropical nutritional neuropathy in Nigerians. Trans. Roy. Soc. Trop. Med. Hyg. 65:454-479.

Oshuntokun, B.O., Monokosso, G.L. and Wilson, J., 1969. Cassava diets and chronic degenerative neuropathy: an epidemiological study. Nigerian J. Sci. 3:3-15.

Oyenuga, V.A., 1955A. Nigerian feedstuffs, University College, Ibadan.

Oyenuga, V.A., and Epeke, L.K., 1957. The value of cassava rations for pork and bacon production. W.Afr.J. Biol. Chem. 1(1):3.

Oyenuga, V.A., and Amazigo, E.V., 1957. A note on the hydrocyanic acid content of cassava (Manihot utillisima Pohl). Biol. Chem. 1(2): 39-43.

Pay, M.G., and Davies, T.E., 1973. Growth, food conversion and carcass characteristics in castrated, and entire males fed three different dietary protein levels. J. Agric. Sci. Camb. 81:65.

Peixoto, R.R., 1965. Comparison of cassava meal as feed for growing and fattening pigs. Escola, Agronom, Elisen, Maciel, Pelotas, Brazil, Nov. P. 19.

Pereira, A.J. and Pinto, M.E., 1962. Determinacao da toxicale de mandioca pelo paladar das raizes 'in natura'. Bragantia 21:145-150.

Pereira, A.J., Nery, J.P. and Igue, T., 1965. Selacao de novos clones de mandioca para mesa, pela toxicidale e paladar de suas raizes - in natura (Determination of edible cassava by tasting fresh roots). Bragantia 24:55-58.

Phillips, T.P., 1974. Cassava utilisation and potential markets. IDRC-020e, Ottawa, Canada.

Pierce, A.B. and Bowland, J.P., 1972. Protein and amino acid levels and sequence in swine diets: Effects on gain, feed conversion and carcass characteristics. Can. J. Anim. Sci. 52:531-541.

Pritchard, P.J., Dryburgh, E.A., and Wilson, B.J., 1973. Carbohydrates of spring and winter field beans (vicia faba, L.) J. Sci. Fd. Agric. 24:663-668.

Rachis, J.J., 1966. Soybean trypsin inhibitors: Their inactivation during meal processing. Food Tech. 20:1482-1484.

Rachis, J.J., 1965. Physiological properties of soybean trypsin inhibitors and their relationship to pancreatic hypertrophy and growth inhibition of rats. Fed. Proc. 24:1488-1493.

Reisen, W.H., Clandinin, D.R., Elvejhem, C.A. and Cravens, W.W., 1947. Liberation of essential amino acids from raw, properly heated and overheated soybean oil meal. J. Biol. Chem. 167:143.

Rerat, A. and Lougnon, J., 1968. Amino Acid requirements of growing pigs. World Rev. Anim. Prod. 4:65-74.

Rerat, A., 1972. Protein nutrition and metabolism in the growing pig. Nutr. Abs. and Review: 42(1):13-39.

Robbins, J. and Rall J.E., 1969. Proteins associated with the thyroid hormones. Physiol. Rev. 40:415-489.

Robbins, J. and Rall, J.E., 1967. The iodine containing hormones in "Hormones in Blood" 2nd ed. Gray, C.H., Bacrach, A.C. (eds) London and New York, Academic Press. P. 383.

Rogers, D.J., 1963a. Studies of Manihot esculenta, Crantz and related species. Bull. Torrey Bot. Club 90(1) 43-54.

Rogers, D.J. and Appon, B.S., 1972. Cassava, the plant, world production and its importance in world food supply, p 1-14 in C.H. Hendershott et al. A liberature review and research. Recommendations on cassava. Univ. of Georgia, Athens, Ga.

Rose, W.C., 1938. The nutritive significance of amino acids. Physiol. Rev. 18: 109-136.

Rutledge, E.A., Hanson, L.E., Meade, R.J., 1961. Protein requirements of suckling pigs. J. Anim. Sci. 20:142-147.

Sarwar, G. and Bowland, J.P., 1976. Protein quality evaluation of low glucosinolate - low erucic acid rapeseed meal and unprocessed faba beans in young pigs. J. Nutr. 106 (3):350-361.

Saunders, J.P. and Himwich, W.A., 1950. Properties of the transsulfurase responsible for the conversion of cyanide to thiocyanate. Amer. J. Physiol. 163:404-411.

Serck-Hanson A., 1970. Aflatoxin-Induced Fatal Hepatitis. Archives Environ. Health 20:729-731.

Shank, R.C., Wogan, G.N., Gibson, J.B. and Nondasuta, A., 1972. Dietary Aflotoxins and Human Liver Cancer. II Aflotoxins in market foods and foodstuffs of Thailand and Hong Kong. Food Cosmet. Toxicol. 10:61-69.

Sinha, S.K. and Nair, T.V.R., 1968. Studies on the variability of cyanoglucoside content in cassava. (Manihot esculenta, Cranz). Ind. J. Agric. Sc. (Dec. 1968).

Smith, C.E., Jr., 1968. The new world centres of origin of cultivated plants and the archaeological evidence. Econ. Bot. 22(3):253-266.

Sreeramamurthy, V.V., 1945. Investigations on the nutritive value of Tapioca (Manihot utilissima). Ind. J. Med. Res. 33:229-238.

Steel, R.G.D. and Torrie, J.H., 1960. Principles and procedures of statistics with special reference to the Biological Sciences. McGraw-Hill Book Co. Inc., New York, Toronto, London.

Stothers, S.C., 1974. Fababeans in swine production. Proc. 1st National Fababeans conf. Marlborough Hotel, Winnipeg, Manitoba. Feb. 21, 22, 1974.

Tanksley, T.D., Jr., 1973. Swine nutrition research. Pfizer 22nd ann. Res. Conf. Chicago, 76-109.

Taurog, A., Wheat, J.D. and Chaikoff, I.L., 1956. Nature of the ^{131}|compounds appearing in the thyroid after injection of iodine^{131}|.

Thrasher, D.M. and Simoneaux, W.D., 1973. Supplementary lysine for barrows and gilts. J. Anim. Sci. 37:292(Abstract).

Toury, J. and Giorgi, R., 1966. Ann. Nutr. Alimentation 20:111.

Velloso, L., Rodrigues, A.J., Becker, M., Neto, L.P., Scott, N.N., Kalil, E.B., Mellotti, L. and Da Rocha, G.L.,

1965/66. Part and complete replacement of maize by cassava in rations for growing and fattening pigs. Bol. Indust. Anim. Sao Paulo, 23:129-137.

Vogtmann, H. Pfirter, H.P. and Prebucki, A.L., 1975. A new method of determining metabolisability of energy and digestibility of fatty acids in broiler diets. Br. Poult. Sci. 16:531-534.

Wahlstrom, R.C., and Libal, G.W., 1973. Lysine and methionine supplementation in swine diets. J. Anim. Sci. 37:393 (Abstract).

Waring, J.J. and Shannon, D.N.F., 1969. Studies on the energy and protein values of soybean meal and two varieties of field beans using colostomised laying hens. Br. Poult. Sci. 10:331-336.

Wilson, B.J., McNab J.M. and Bentley, H. 1972. Trypsin Inhibitor activity in the field beans (Vicia faba L). J. Sci Food Agric. 23:679-684.

Winton, A.L. and Winton, K.B., 1935. "The Structure and Composition of foods" John Wiley and Sons, Inc., N.Y. 1935.

Wokes, F., and Pickard, C.W., 1955. The role of vitamin B12 in human nutrition. Amer. J. Anim. Nutr. 3:383-390.

Wolff, E.C., and Wolff, J., 1964. The mechanism of action of the thyroid hormones. In "The Thyroid Gland," Vol 4, Pitt-Rivers, R, Trotter, W.R. (eds.) New York, Butterworth and Co., 1964. P. 237.

Wood, T., 1965. The cyanogenic glucoside content of cassava and cassava products. J. Sci. Food Agr. 16:300-305.

Wood, J.L. and Fielder, H. 1953. B-mercaptopyruvate, a substrate for rhodanase. J. Biol. Chem. 205:231-234.

Woodman, H.E. and Evans, R.E. (1940). The nutrition of the bacon pig (v). The minimum level of protein intake consistent with quick growth state, and satisfactory carcass quality, (part 2). J. Agric. Sci. 30:83-97. Part 3. J. Agric. Sci. 31:232-245. Part 6. J. Agric. Sci. 35:133-149. Part 1. J. Agric. Sci. 29:115-130.

Woodman, H.E., Manzies Kitchin, A.W. and Evans, R.E., 1931. The value of Tapioca flour and sago pith meal in the nutrition of swine. J. Agric. Sci. 21:526.

Wyllie, D., Speer, V.C., Ewan, R.C. and Hays, V.W., 1969. Effects of starter protein level on performance and body composition of pigs. J. Anim. Sci. 29:433.

Young, G.L., 1970. Processing of Soybeans for swine. Feedstuffs, 42(12): 234-237.

Young, L.G. and Smith, G.C., 1973. Processing soybeans with sodium hydroxide and copper sulphate for pigs. Can. J. Anim. Sci. 53:587.

Zimmerman, D.R. and Khajarern S. 1973. Starter protein nutrition and compensatory responses in swine. J. Anim. Sci. 36:189-194.

APPENDIX 1

Grading

Aherne et al. (1974) reviewed the hog grading system in Canada. The system is based on total backfat measurements and dressed carcass weight. The total backfat is the sum of the measurements of maximum depth of shoulder fat and the maximum depth of loin fat. Carcasses weighing between 150-159 pounds and having an average total backfat of 3.2-3.3 inches are given an index of 100. The index changes for every two-tenths of an inch of backfat and nine carcass weight brackets (range 90 lb to over 196 lb). The different combinations of backfat and carcass weight are given indexes ranging from 87-112. Thus pigs having low backfat and carcass weights between 150-180 lb receive the highest index rating. The market price of pigs is based on carcasses with an index of 100 and a carcass receiving an index of 110 would receive 10% more per pound than the base market price. Similarly a carcass with an index of 90 would receive 10% less per pound than the market price.

Record of Performance (R.O.P.) System

Canada approved a revised Record of Performance Testing of Swine in 1971. It involves the use of a carcass score which provides an estimate of the combined yield of the four lean cuts of the carcass. This score is derived from the following:

1. Carcass length - measured in inches from the front

of the first rib to the aitch bone.

2. Total backfat (measured at 3 points - sum of the maximum shoulder and loin fat plus minimum visible midback fat).
3. Area of loin.
4. Percent ham of side.
5. Ratio of lean area in face of ham and weight of ham.

The following formula is then used to estimate the percentage yield of trimmed cuts in the carcass.

$$ROP\ y = 51.68 - (3.234 \times X) + (1.038 \times X) + (0.485 \times X) + (11.766 \times X) + E$$

where 51.68 = a constant term, estimated yield

X = total fat (3 measurements)

X = loin area

X = percent ham of carcass

$$X = \frac{\text{area of lean in ham face}}{\text{ham weight}}$$

E = sex correction factor
(+1.1% for barrows, -1.1% for gilts)

At the present time, this index is too elaborate for use in routine grading of market pigs, but is useful in assessing pig carcasses in nutritional research studies.

Appendix TABLE 1

MEAN SQUARES AND PROBABILITY FOR STARTING PHASE

SOURCE OF VARIATION	d.f.	A D F		A D G		E F C	
		M.S.	Prob.	M.S	Prob.	MS	Prob.
Treatment	14	0.094021	0.0019***	0.07799	0.0000***	5.9716	0.0000***
Rep	1	0.078128	0.0985	0.03237	0.0557	0.48650	0.4660
R T	14	0.026724	0.4822	0.014648	0.0880	0.92443	0.4472
Error	30	0.026863		0.0081717		0.89213	

Appendix TABLE 2

MEAN SQUARES AND PROBABILITY FOR FINISHING PHASE

SOURCE OF VARIATION	d.f.	A D F		A D G		E F C	
		MS	Prob	MS	Prob	MS	Prob
Finishing (trt)	4	0.6044	0.000***	0.0698	0.000***	0.0215	0.4350
Replicate	1	0.0029	0.657	0.0818	0.2328	0.0053	0.6270
Error	14	0.014		0.0012		0.0213	

TOTAL GAIN

SOURCE OF VARIATION	d.f.	MS	Prob
Finishing	4	542.87	0.002**
Replicate	1	86.36	0.295
Error	14	73.08	
Sex	1	184.51	0.03
SF	4	33.83	0.468
SR	1	4.96	0.717
Error	60-4=56	40.13	

Appendix TABLE 3

MEAN SQUARES AND PROBABILITY FOR DIGESTIBILITY STUDIES

SOURCE OF VARIATION	d.f.	% DE		% DN	
		M.S	Prob.	M.S.	Prob.
Methods	1	416.19	0.0000***	524.42	0.0000***
Treatment	14	20.911	0.0065**	17.482	0.2976
M T	14	13.990	0.0802	20.431	0.1790
Rep.	1	14.214	0.1942	16.711	0.2880
M. R.	1	14.394	0.1914	18.330	0.2660
TR	14	14.349	0.0708	26.893	0.0516
MTR	14	8.4453	0.4425	10.919	0.7152
Error	60	8.2439		14.538	

Appendix TABLE 4

MEAN SQUARE VALUES FOR CARCASS CHARACTERISTICS

	Treatment	Replicate	Sex	STR	Error
d.f.	4	1	1	4	100
Live weight	236.11	3.367	12.352	18.616	41.154
Carcass wt	201.07	33.37	9.219	13.277	28.689
Dressing %	8.802	21.99	0.3730	1.748	1.872
Total backfat	2.960	0.039	0.233	0.013	0.476
Length of side	37.268	60.54	3.26	1.82	6.49
Ham wt/carcass wt	1.720	7.505	3.231	0.988	1.506
Area of loin	67.46	36.11	39.64	12.19	12.65
Lean in Ham face	52.760	87.52	28.50	64.50	30.71
Lean area Ham/Ham wt	10.87	0.141	0.493	4.49	3.21
Slaughter age	13006	1197.0	1.408	330.01	178.25
Grade Index	83.55	33.08	54.68	30.88	21.40